BASIC RESEARCH PLAN

DEPARTMENT OF DEFENSE
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BRP

OFFICE OF THE SECRETARY OF DEFENSE

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This edition of the Department of Defense (DoD) *Basic Research Plan* continues the evolutionary planning process that we have created to integrate more effectively the comprehensive range of activities composing our corporate science and technology program. It contains an expanded section on selected basic research accomplishments, updated budget and funding information, more details on how the Military Services conduct research planning and evaluation activities, and many new graphics. The plan is the product of Army, Navy, Air Force, and Defense Agency basic research program managers working together in the context of both Defense Science and Technology Reliance and the Defense Committee on Research.

The *Basic Research Plan* sets forth our overall strategy for conducting a comprehensive research program able to provide a strong foundation for subsequent technological advances and the development of new military capabilities and systems. The document describes work involving twelve technical disciplines that span the great majority of the scientific activities in the DoD basic research program, and it formulates broad visions of what might be achieved in each of these areas. These visions are broad by necessity. While research is richly productive, results are unpredictable. Thus, our visions will evolve--even abruptly change--over time.

This edition of the *Basic Research Plan* reflects our continuing development of a number of specific strategic research objectives that define rapidly expanding research fronts with the potential for high military benefit, rich with scientific opportunities that cut across multiple fields of science.

The *Basic Research Plan* is a working document. As a product of corporate planning, it provides guidance to the Military Services and Defense Agencies to help ensure that their combined research efforts will enable our primary customer--the warfighter--to maintain a military advantage important to our national interests and security well in to the future.

Anita Jones

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COMMENTS FROM THE DEFENSE COMMITTEE ON RESEARCH

In 1993 the Director of Defense Research and Engineering initiated a corporate science and technology (S&T) planning process designed to more effectively link the products of the Defense S&T Program with the needs of the warfighter. The foundation of this process is the *Defense Science and Technology Strategy* supported by the *Joint Warfighting Science and Technology Plan*, the *Defense Technology Area Plan*, and this second edition of the *Basic Research Plan*. These documents present the DoD S&T vision, strategy, plan, and objectives for the planners, programmers, and performers of defense S&T. Revised annually, these documents are a collaborative product of the Office of the Secretary of Defense, Joint Staff, military Services, and Defense Agencies.

The strategy and the three plans are fully responsive to the Chairman of the Joint Chiefs of Staff's vision as presented in *Joint Vision 2010*, and the White House National Security S&T Council's *National Security Science and Technology Strategy*. The strategy, plans, and supporting individual S&T master plans of the military Services and Defense Agencies guide the annual preparation of the DoD program and budget.

The *Basic Research Plan* presents the DoD objectives and investment strategy for DoD-sponsored research performed by universities, industry, and government laboratories. In addition to summarizing the planned investment in twelve broad research areas, the plan highlights six Strategic Research Objectives holding great promise for the development of enabling breakthrough technologies.

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Basic Research Plan

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DEPARTMENT OF DEFENSE
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CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The DoD Basic Research Program has long played a crucial role in the development of technology and in the education and training of scientific personnel required to support continuing technical advances critical to maintaining superior military capabilities. This *Basic Research Plan* (BRP) provides a strategy for maintaining a strong program that is flexible with respect to current budget priorities but also structured to effectively respond to requirements of the warfighter. The BRP complements two other DoD Science and Technology (S&T) planning documents: the *Joint Warfighting Science and Technology Plan* and the *Defense Technology Area Plan*. Together the three documents reflect a comprehensive strategic planning process designed to significantly enhance the quality of the overall S&T program.

The basic research strategy presented in this plan is derived from warfighting requirements identified by the Chairman of the Joint Chiefs of Staff as part of *Joint Vision 2010*. This conceptual framework is intended to provide common direction for the services in pursuing information superiority and technological innovations capable of supporting and producing powerful new warfighting strategies. Basic research provides a firm foundation for such advances and technological innovation, and steady progress will be maintained by following a strategy for supporting world-class research that consists of four main components:

- Execute a superior quality, competitive, multifaceted research program.
- Maintain a flexible and balanced investment portfolio.
- Sustain an essential research infrastructure.
- Conduct visionary planning, resource-constrained prioritization, and oversight.

An important part of the strategy is to provide a sharper focus for certain research activities by establishing a number of Strategic Research Objectives (SROs) in selected multidisciplinary areas considered to offer significant and comprehensive benefits to our military capabilities. Research accomplishments in some of these fertile areas have already had a significant impact on technology areas such as advanced structures and new classes of sensitive detectors. The SRO areas are part of the long-term broad and diverse DoD research and education agenda. They provide an important flexible and focused complement to the majority of Basic Research Program activities that seek to exploit opportunistic synergies and technologies and that may take longer to mature. The SROs identified and described in this BRP include:

- ***Biomimetics***—enable the development of novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.
- ***Nanoscience***—achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).
- ***Smart Structures***—demonstrate advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multi-element, deformable structures used in land, sea, and aerospace vehicles and systems.

- ***Mobile Wireless Communications***—provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, graphics, and video) from point to point, broadcast and multicast over distributed networks for heterogeneous C^3I systems.

- ***Intelligent Systems***—enable the development of advanced systems able to sense, analyze, learn, adapt, and function effectively in changing or hostile environments until completing assigned missions or functions.

- ***Compact Power Sources***—achieve significant improvements in the performance (power and energy density, operating temperature, reliability and safety) of compact power sources through fundamental advances relevant to current technologies (e.g., batteries and fuel cells) and the identification and exploitation of new concepts.

The BRP includes a comprehensive and detailed presentation of ongoing research activities and plans, funding levels, and specific research objectives for each of the twelve technical disciplines composing the Basic Research Program. Special aspects of the program such as the University Research Initiative (URI) are also reviewed. The BRP concludes with a description of selected basic research successes funded by the Army Research Office (ARO), the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Defense Advanced Research Projects Agency (DARPA), and the Ballistic Missile Defense Organization (BMDO). These examples underscore the continuing importance of basic research contributions to meeting both current and future U.S. defense needs.

1.0 INTRODUCTION

Over the last few years, the Director of Defense Research and Engineering (DDR&E) has guided the continuing evolution of a corporate science and technology (S&T) strategic planning process designed to enhance the quality of the S&T program and more effectively link the products of the program with the needs of the warfighter. This process addresses the Joint Chiefs of Staff (JCS) *Joint Vision 2010* with a sound Department of Defense (DoD) S&T strategy linked to specific technology objectives via "technology roadmaps." When DoD-sponsored basic research is integrated into this overall planning process, the relevance of research becomes more explicit than ever before.

This *Basic Research Plan* (BRP) is the third element of the DoD S&T program planning triad, the other two elements being the *Joint Warfighting Science and Technology Plan* (JWSTP) and the *Defense Technology Area Plan* (DTAP). This natural linkage highlights the fact that basic research is the cornerstone of the DoD S&T investment. Together the three documents describe a comprehensive strategy and plan for the overall S&T program.

Basic research has its own unique characteristics, however, and no strategy can accurately capture the synergistic and unpredictable nature of innovation and discovery. By their nature, the end products of basic research are sometimes difficult to predict and often result in applications not originally envisioned. We can only provide broad and constant support to allow this complex and serendipitous process to occur, wherein seemingly unimportant elements often provide significant benefits over the long term. For example, packet switching research funded by the Defense Advanced Research Projects Agency (DARPA) more than 20 years ago led to the evolution of the Internet. Likewise, molecular spectroscopy research conducted as part of the Joint Services Electronics Program (JSEP) led to the development of the laser; various types of lasers are currently used in rangefinders, airborne minesweepers, communications systems, and other military equipment. Yet research in lasers continues today because there are still important breakthroughs to be made. The products of basic research can also feed directly into existing military systems.

Consequently, the Basic Research Program must initiate and sustain both *evolutionary* research responsive to recognized needs of current military systems, as well as *revolutionary* research not specifically focused on current military applications but capable of providing exciting new opportunities for meeting our future defense requirements. The basic research strategy must strive to maintain and strengthen in-house laboratory research capabilities as a foundation for subsequent applied research and systems development activities. It must encourage collaborative efforts and partnerships among DoD laboratories, universities, and industry. It must further leverage and enhance our national research assets by exploiting knowledge from the international scientific community. The strategy must also contribute to ensuring the continuing availability of competent young scientists and engineers, as well as high-quality research facilities, to the DoD research community through significant and unwavering support of university-centered research. Over the last few decades, such support has enabled many of this nation's scientific and engineering leaders to earn graduate degrees.

An effective research strategy must remain responsive not only to historical threats but also to new threats and challenges brought on by global influences and shrinking defense budgets. Now, more than ever, our basic research investments must be aimed at securing warfighting capabilities

most needed by our military in the future, as identified in the JCS *Joint Vision 2010*. Meeting recognized needs and achieving critical new capabilities requires leveraging technological advances and information superiority with the traditional operational concepts of maneuver, strike, protection, and logistics. Consequently, powerful and new operational concepts emerge:

- ***Dominant Maneuver***—the multidimensional application of information and maneuver capabilities to provide coherent operations involving land, sea, air, and space forces throughout the breadth, depth, and height of the battlespace, thereby enabling our forces to seize the initiative, control the tempo of the operation, and achieve a decisive conclusion.
- ***Precision Engagement***—the capability to accurately locate the enemy, effectively command and control our forces, precisely attack key enemy forces or capabilities, and accurately assess the level of success.
- ***Full-Dimensional Protection***—the ability to protect our forces at all levels and obtain freedom of action while they deploy, maneuver, and engage an adversary.
- ***Focused Logistics***—the capability to respond rapidly to crises, shift warfighting assets between geographic routes, monitor critical resources enroute, and directly deliver tailored logistics at the level required by operations.

Our potential adversaries are continuing to reap the benefits of a worldwide proliferation of high-technology weapons and systems. Unless DoD can sustain a stable investment in research, the superior technological prowess of our warfighting units will eventually erode. Current DoD planning directives call for this investment to remain steady, growing only with inflation, for the foreseeable future. This *Basic Research Plan* presents a wide-ranging strategy for making wise investment choices in implementing and maintaining all aspects of the Basic Research Program. Its effective execution will help to ensure that the current technological superiority of our warfighters can be maintained well into the future.

2.0 DOD BASIC RESEARCH STRATEGY

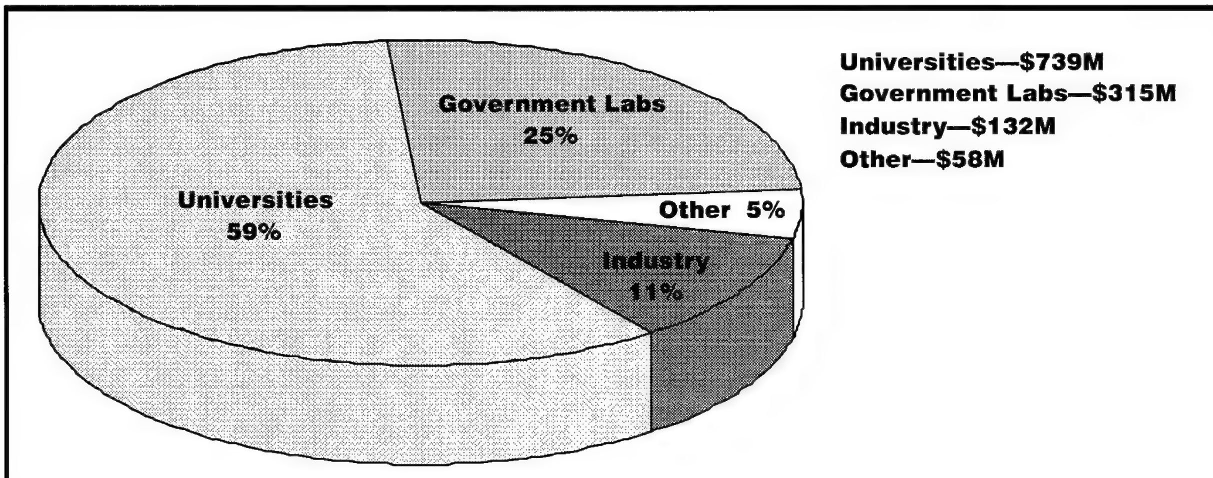
The primary objective of the DoD basic research strategy is to provide the means for conducting world-class research that enables new technologies and capabilities to be developed and used by the warfighter in order to maintain a technologically superior military force. Defense-sponsored research creates future technology opportunities. To achieve this objective, a strategy has been devised consisting of four components:

- Execute a superior quality, competitive, multifaceted research program.
- Maintain a flexible and balanced investment portfolio.
- Sustain an essential research infrastructure.
- Conduct visionary planning, resource-constrained prioritization, and oversight.

2.1 Major Strategy Components

2.1.1 Execute a Superior Quality, Competitive, Multifaceted Research Program

DoD recognizes that universities, in-house DoD laboratories, and industry are all vitally important to the Basic Research Program. University centers, federated laboratories, consortia, individual academic investigators, and industry are all modes of conducting research that are addressed by this strategy. DoD will continue to invest broadly across a wide range of technical disciplines and achieve scientific and technological advances by supporting the best research performers. Where appropriate, special programs will bring various types of performers together to achieve specific technical or functional goals. DoD laboratories operated by the military departments will be both performers and purchasers of research and technology. Investments will be made in these facilities for doing research that would not be accomplished elsewhere. Figure 2–1 illustrates how DoD invested its FY95 basic research dollars across various types of performers.



Source: *Science and Engineering Indicators—1996*, National Science Board

Figure 2–1. FY95 DoD Basic Research Funding by Performer

This component of the basic research strategy will use competition as an important tool in promoting quality research. When seeking new ideas, DoD will use the broad agency announcement (BAA) process, electronic media, and other mechanisms to reach the largest possible segment of the scientific research community. Awards are made using competitive procedures. As appropriate, DoD in-house research activities will continue to be subjected to peer review and selection on a competitive basis.

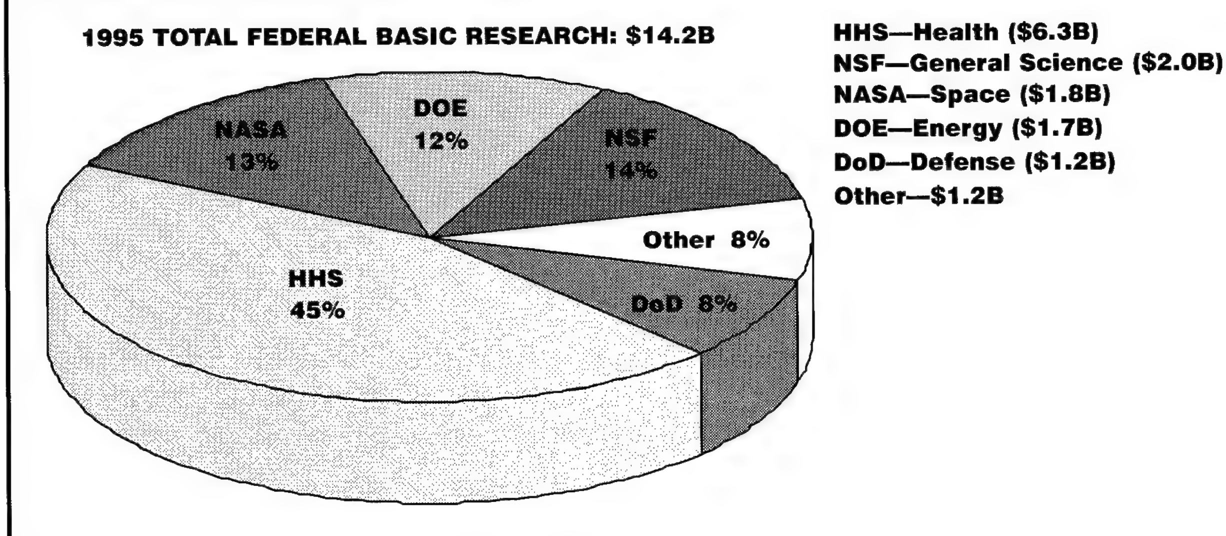
Over 59 percent of all DoD basic research funding is spent at universities. Universities are key performers of research for DoD. Over the past 15 years, science and engineering research at universities has expanded to fill many gaps left by the reduction in basic research performed by industry. Universities have become partners with industry in providing the innovation for military technology in such areas as lasers, electronics, computing, and materials. *Science* magazine reports that over 35 percent of all patents issued to industry are the result of collaboration with universities, and the percentage is growing.

DoD in-house laboratories provide the technical expertise to enable the military services to be smart buyers and users. The DoD laboratories perform three critical functions: (1) identifying the connections between warfighters' needs and technological opportunity, (2) responding with high-quality research solutions to the warfighter's needs in areas where no external performer can reliably assist, and (3) providing continuity and direct support to acquisition commands—program executive officers and program managers—through technical expertise, contract management, work force training, and staff support. For example, the Army emphasizes information technologies (mathematics, computer science, electronics) for digitizing the battlefield, materials science for armor and soldier protection, optical sciences for target recognition, chemistry and biological sciences for chemical and biological agent defense, and geosciences for terrain-related knowledge relevant to battlefield mobility prediction. The Navy has a full-spectrum program that places special emphasis on a wide range of ocean science activities, including predicting weather and currents, mapping the ocean floor, using acoustics to detect objects in the ocean, and conducting biotechnological research such as understanding and mimicking communications between mammals. Air Force expertise is concentrated in the aerospace sciences, materials, physics, electronics, chemistry, life sciences, and mathematics for application to air vehicles, space systems, and communications, command, control, computers, and intelligence (C^4I). Besides directly supporting their military departments, DoD laboratories act as agents for DARPA, the Ballistic Missile Defense Organization (BMDO), and other defense agencies with research and technology development functions.

Finally, the DoD basic research strategy will leverage industrial and international research efforts through cooperative and joint programs. DoD will continue to offer guidance and review industry Independent Research and Development (IR&D) programs that offer potential military application.

2.1.2 Maintain a Flexible and Balanced Investment Portfolio

DoD will continue its long-term research investment in core scientific disciplines. Concurrently, investments will be made in technical areas pertinent to identified Strategic Research Objectives (discussed in Chapter 3) or high-profile scientific areas of strong military relevance that are focused and that exploit research advances in multiple core disciplines. Figure 2–2 shows the distribution of overall FY95 federal funding for basic research. Although the figure reveals that DoD provides less than 10 percent of all federal basic research funding, it is important to realize that DoD



Source: *Federal Funds for R&D*, NSF Report 95-334

Figure 2-2. FY95 Federal Basic Research Funding (6.1 Budget Category)

is a major source of federal funding of R&D at universities in a number of critical fields, including computer sciences, electronics, optics, materials, aerospace engineering, and oceanography. Historically, DoD spends its research dollars supporting the scientific and engineering disciplines that can most significantly impact future warfighting capabilities. When 6.1 (Basic Research) and 6.2 (Applied Research) funding levels for FY95 are combined, the specific percentages of DoD investments in various scientific fields are as indicated in Table 2-1. For example, in FY95, DoD invested about 15.2 percent of its total 6.1 and 6.2 funding in mathematics and computer science, but this represented 42.4 percent of all federal funding in this scientific area. Overall, DoD's investment in all of the areas indicated in Table 2-1 represented 15.1 percent of the total federal investment for basic and applied research.

Table 2-1. DoD Support for Basic and Applied Research (FY95)

Field	Percentage of Support Within DoD Funding	DoD Investment as a Percentage of All Federal Funding
Life Sciences	7.6	2.8
Cognitive Sciences	2.3	17.0
Physical Sciences	14.4	14.0
Environmental Sciences	6.0	9.5
Mathematics/Computer Science	15.2	42.4
Engineering	50.6	38.4
Social Science	0.3	1.9
Other	3.6	14.4

Source: *Selected Data on Federal Funds for Research and Development*, National Science Foundation, NSF Report 95-321.

DoD basic research will focus on a variety of military problems, some requiring near-term, immediate, or partial solutions, and others requiring sustained investment over longer periods to attain success. Long-term research in a dozen scientific disciplines will address enduring military requirements such as improved information systems, sensors, advanced electronics, and materials.

The DoD Basic Research Program will achieve depth in critical areas with obvious military potential, yet maintain breadth, by leveraging research in other federal agencies and research entities and the international scientific and engineering community. DoD will encourage innovation by maintaining flexibility to invest in promising areas of research that do not easily fit into established programs. Care will also be taken to consider nonmilitary applications of basic research results and, where appropriate, to ensure that accomplishments undergo transition into the civilian sector.

2.1.3 Sustain an Essential Research Infrastructure

Students, modern equipment, and facilities are necessary ingredients for future DoD research. The Basic Research Program will provide for the education and involvement of graduate students and young investigators through a variety of policies and programs designed to create new generations of scientists and engineers. In addition, DoD will maintain continuing education programs for its own technically trained employees, who make up almost half the number of scientists and engineers employed by the federal government. Figure 2–3 illustrates the strength of the long-standing DoD commitment to support graduate students in science and engineering.

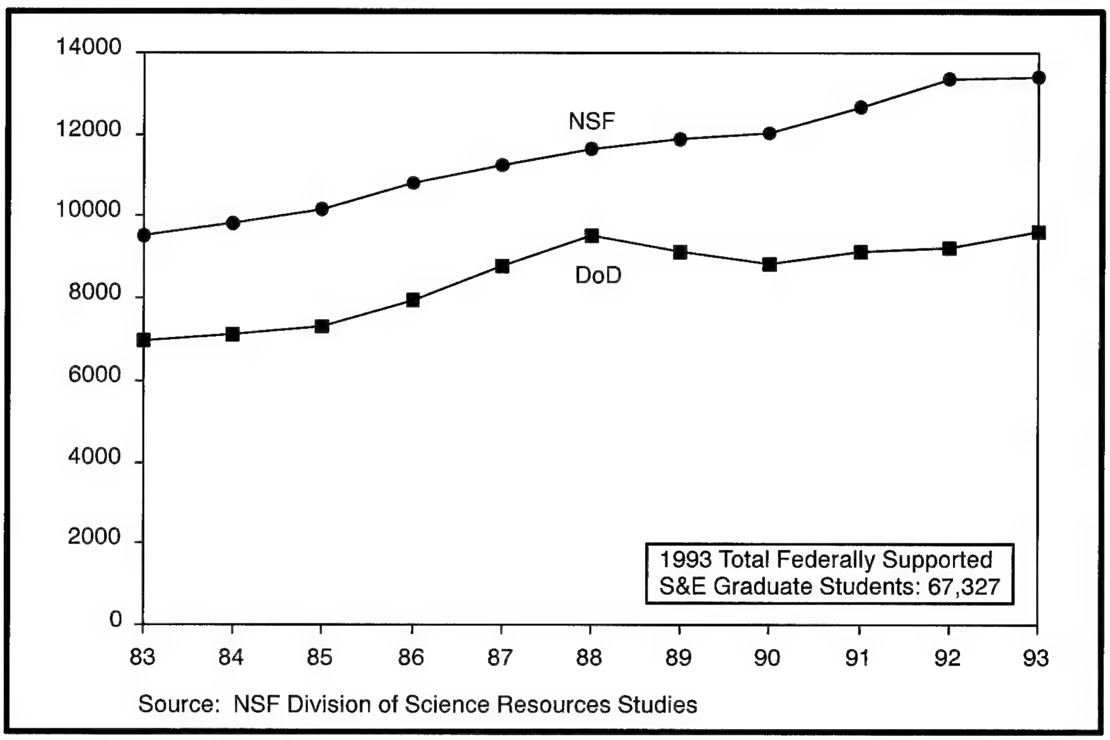


Figure 2–3. Supported Science and Engineering Graduate Students

Special equipment programs will link purchases of modern research tools to programs. In some cases, unique and essential facilities may be upgraded or created. Like other elements of the

DoD infrastructure, the laboratories are participating in the processes of reinvention and acquisition reform. The laboratory work force is being reduced, the facilities infrastructure is being reorganized, and opportunities for consolidation and cross-service integration are being examined. Accompanying this reduction in size are new personnel demonstration systems designed to reinvigorate in-house quality and new organizational structures and acquisition procedures that stress interaction and partnership with extramural performers.

DoD recognizes the importance of Historically Black College and University/Minority Institution (HBCU/MI) programs for the future of basic research and will strive to provide opportunities to minority groups through programs that build infrastructure and through ties to core research efforts. In the past, these programs have provided approximately $60 million annually to fund individual researchers, research consortia, instrumentation purchases, and the creation of selected topical science and technology centers at eligible institutions. These programs are partially funded in the basic research category ($10.8 million in FY97) and are administered by the DDR&E(Research) organization.

2.1.4 Conduct Visionary Planning, Resource-Constrained Prioritization, and Oversight

DoD will continue to plan its research through a blend of top-down guidance and bottom-up innovation. The BRP will be linked to the National Security S&T Strategy, the JCS *Joint Vision 2010*, the JWSTP, the DoD S&T Strategy, and the DTAP. This relationship is shown in Figure 2–4. Together, these documents will provide a basis for consistent planning across all facets of the S&T Program. The Basic Research Program will be reviewed each year by ODDR&E through the Technology Area Review and Assessment (TARA) process to provide guidance for Program

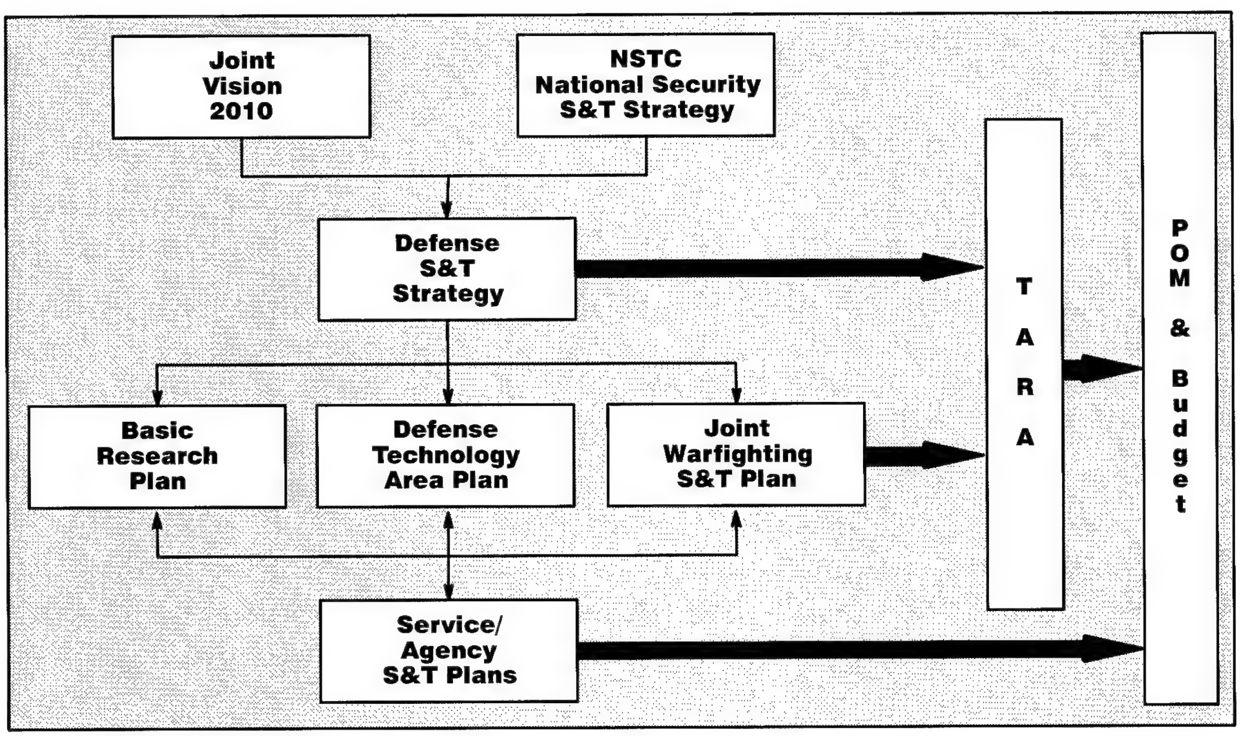


Figure 2–4. DoD Science and Technology Strategy Planning Process

Objective Memorandum (POM) submission and priorities for major program elements. This review focuses on research quality and relevance to military requirements using the BRP as the 6.1 analog to the DTAP and an important source document for the TARA process. Quality and relevance will be ensured through periodic reviews of all research efforts by expert panels of representatives from other services and government agencies, industry, and academia. The BRP is guided by input from the *Defense Science and Technology Strategy* and the DDR&E S&T annual guidance letter, as well as by feedback from the TARA review. Figure 2–5 depicts the annual review and analysis cycle for the S&T program.

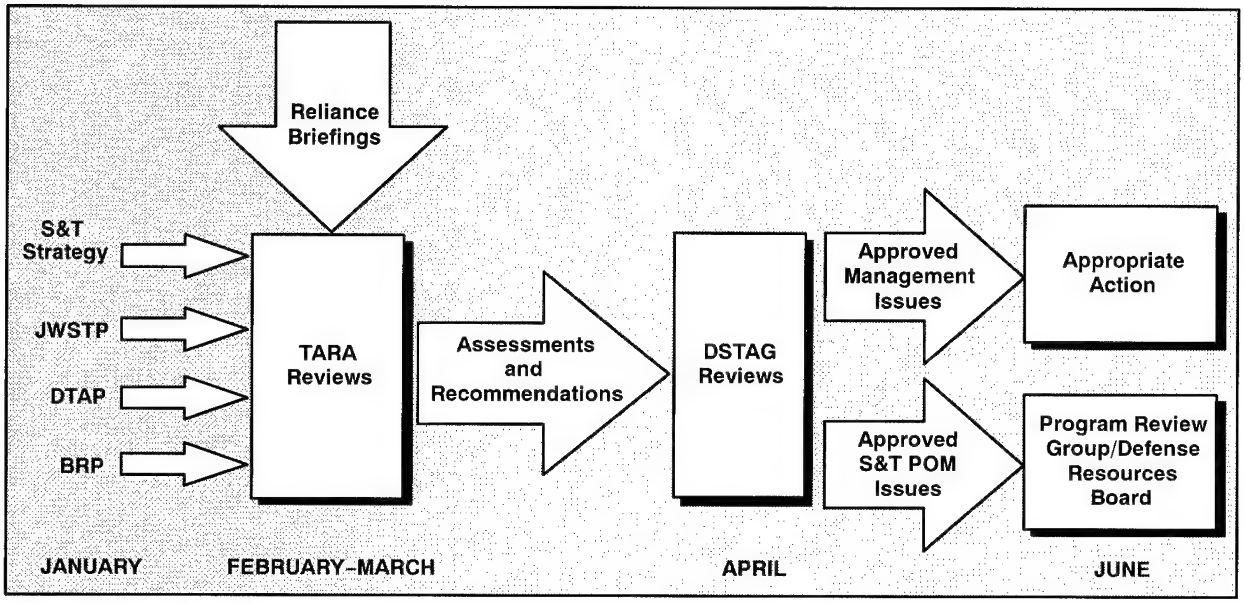


Figure 2–5. TARA Process in Context

The BRP is developed, coordinated, and implemented by the military services and defense agencies through a group called the Defense Committee on Research (DCOR). The services are responsible for training and equipping the military forces; they rely on the S&T program to provide warfighting and system options for their components. The defense agencies are responsible for certain multi-service aspects of S&T as well as for designated programs that support national security objectives. Members of the DCOR are:

- Director for Research, ODDR&E (Chairman)
- Director, Army Research and Laboratory Management
- Director, Army Research Office (ARO)
- Associate Technical Director for Development, Office of Naval Research (ONR)
- Director, Air Force Office of Scientific Research (AFOSR)
- Director, Electronics Technology Office, DARPA
- Director, Science and Technology, BMDO.

Current members of the DCOR are identified in Appendix A, which includes mailing addresses and phone, fax, and e-mail information.

The annual basic research review cycle starts with project-level reviews at the individual research agencies (ARO, ONR, AFOSR). These sessions are followed by a program-level review of the combined research agencies and preparation of the *Basic Research Plan*. Budget projections for the next year are then prepared and submitted. The performance of the Basic Research Program with respect to inter-defense agency coordination and guidance from the DoD S&T strategy is evaluated by DDR&E, with feedback to the agencies after the annual program review. The services and defense agencies also conduct their own periodic program reviews to assess quality, relevance, and scientific progress.

A significant aspect of the DoD basic research strategy involves the role of Reliance. In 1995, the DDR&E adopted the goals and structure of the S&T Reliance initiative, and the Deputy Director, Defense Research and Engineering (DDDR&E) assumed the chair of the Defense S&T Reliance Executive Committee (EXCOM). The new DDR&E-led S&T strategy and planning process focuses on ensuring the transition of technology to address warfighting needs, strengthening the commercial-military industrial base, promoting basic research, and ensuring quality throughout the entire DoD S&T community.

Defense S&T Reliance is a set of agreements established among and implemented by the military departments for joint planning, co-located in-house work, or lead-service assignments that cover the majority of non-service-unique portions of the services' 6.1 (Basic Research), 6.2 (Applied Research), and 6.3 (Advanced Technology Demonstration) S&T programs. Basic research, functioning as a separate area, is organizationally composed of twelve technical disciplines. These disciplines are discussed in Section 4 of this plan. Each area has been examined closely by its participants to establish areas of common interest. Such joint planning and coordination of programs precludes undesired duplications of individual service efforts.

2.2 Basic Research Planning in the Services

Each service independently plans and reviews its own basic research activities. Although elements of each program may be unique or have a research component that emphasizes an area of particular relevance to a specific service, the planning and review process carried out by each service is uniformly similar and consistent.

A common theme among all three services is that basic research planning is not treated as a stand-alone entity. Rather, it is integrated and embedded into the more comprehensive planning and review process of each service's overall S&T program. That integration is evident in the *Army S&T Master Plan*, the *Air Force S&T Research Technology Area Plan*, and the *Navy S&T Strategy*. Each of these S&T plans is produced annually. The development of the S&T plans and the cycle of DoD and service program reviews and oversight result in a planning process that is essentially continuous throughout the year. The service S&T plans derive much of their direction from the DoD S&T Strategy. In return, these S&T plans serve as primary inputs to the JWSTP and the DTAP.

Basic research planning in the services involves the combined efforts of many individuals and organizations. The single most important entity in this process is each service's customer—the warfighter. The warfighter's needs and requirements are the overarching focus of the Basic Research Program. The warfighter is involved early in the planning process where military requirements are developed and established. In general, the warfighter's participation continues as part of the review and oversight process to ensure that research efforts are specifically directed to enhancing military

capability. To a lesser extent, scientists in academia and industry contribute to the review and oversight process by serving as occasional advisors to members of the Scientific Planning Groups (SPGs) and through participation in technical workshops, review panels, and the ODDR&E TARA process.

Although commercial applications that arise from service basic research activities are encouraged, these occurrences are difficult to predict. The services do not fund a basic research area solely on the basis of its dual-use potential. What is of prime importance in selecting areas for research is the quality of the science and the relevance to the service's military requirements. These two qualitative measures of effectiveness are used to evaluate research progress and to modify ongoing basic research efforts when appropriate.

Contingency planning is another common element in each service's approach to planning basic research. Budgetary and resource constraints, unplanned military situations, and dramatic scientific breakthroughs can impact any plan no matter how well thought out. Unplanned situations force adjustments to planned basic research activities by either reducing or increasing service investment in various areas. The services account for these contingencies by prioritizing their individual research efforts. When funds must be redistributed to either accelerate a promising research area or to support unexpected military operations, lower priority programs are eliminated or modified significantly.

The basic research activities of the services leverage each other as well as relevant programs in other parts of government. Joint activities include technical conferences, sharing of special test facilities and laboratories, and joint publication of technical papers. Service coordination is fostered through meetings of the DCOR, S&T Reliance, and Scientific Planning Groups (SPGs). Intra- and inter-service considerations are equally important in the basic research planning process.

One notable difference in overall program planning by the services involves the varied approaches adopted for enhancing mainline basic research activities and helping to accelerate technology transfer. The Army, for example, has developed an open federated laboratory system to access and leverage the expertise of industry and academia in selected areas such as advanced displays, sensors, telecommunications, and other application-oriented technologies that form the foundation for Force XXI and Army After Next (AAN). The Navy has opted to fund certain accelerated capability initiatives (ACIs) that focus on priority requirements having the potential to break existing paradigms; about 5 percent of the Navy's basic research budget is directed toward such efforts, which are integrated 6.1/6.2/6.3 programs that combine insights gained in the requirements process with interactions involving the warfighter and the Navy acquisition community. The Air Force has recently established a Program for Research Excellence and Transitioning (PRET) to facilitate more rapid transition of university research to the defense industry by providing larger grants to universities that allow for active collaboration between industrial and academic researchers. PRET grants also support two-way exchange of personnel; facilitate the use of specialized industrial equipment for characterization and other evaluations; and promote the availability of candidate chemicals, materials, devices, concepts, and designs from industry for consideration in academic research programs.

2.3 Coordination and Funding of Basic Research Disciplines

Most of the DoD Basic Research Program is managed and coordinated through ten SPGs that include representatives from the three services. The SPGs cover all twelve of the technical

disciplines composing the Basic Research Program and are specifically defined for Physics, Chemistry, Mathematics and Computer Science, Electronics, Materials Science, Mechanics, Ocean and Terrestrial Sciences, Atmospheric and Space Sciences, Biological Sciences, and Cognitive and Neural Science. The SPGs ensure the coordination of basic research among the services and defense agencies. The SPGs also coordinate with managers of the DoD technology area plans to help ensure the transition of basic research results into applied research programs. For FY96, funding totals for the twelve basic research areas managed and coordinated through the SPGs were as follows:

Research Area	$ Millions[1, 2]
Physics	65.7
Chemistry	61.3
Mathematics	51.3
Computer Science	39.4
Electronics	98.1
Materials Science	59.6
Mechanics	97.4
Terrestrial Sciences	23.7
Ocean Sciences	92.5
Atmospheric and Space Sciences	43.7
Biological Sciences	67.7
Cognitive and Neural Science	31.2
	731.6

[1] DARPA funding for basic research in Computer Science, Electronics, and Materials Science is provided in Table 2–2.

[2] Educational and HBCU/MI programs funded by the services are not included in these totals, which accounts for the difference between this tabulation and the total cited for the services in Table 2–2.

Information regarding current membership of the SPGs is provided in Appendix A.

2.4 Relationship to 6.2 and 6.3 Programs

The Basic Research Program is funded under DoD's 6.1 budget activity. The program serves as a strong foundation for the acquisition process by providing significant innovation and technological opportunities for subsequent use in 6.2 (Applied Research) and 6.3 (Advanced Technology Demonstration) programs. The scientific objectives of the basic disciplines and the Strategic Research Objectives support multiple defense technology objectives in the DTAP and the JWSTP. Researchers and research program managers encourage the military and technology development community to facilitate transition of the more mature research results, including preliminary assessment and evaluation, and the development of requirements. The output of basic research usually affects multiple technology objectives and potential military applications. This broad applicability is focused on the most promising avenues by collaboration between the research managers and the planners of 6.2 and 6.3 programs. In certain instances, results of basic research can even influence 6.4 (Engineering Development) programs and fielded systems.

2.5 Elements of the Basic Research Program

The Basic Research Program is composed primarily of three elements: Defense Research Sciences (DRS), In-house Laboratory Independent Research (ILIR), and the University Research Initiative (URI). Funding profiles for the total DoD Basic Research Program, broken out by major program component as well as by specific service and defense agency, are shown in Table 2–2.

2.5.1 Defense Research Sciences

Collectively, the DRS programs supported by the services, DARPA, and the Office of the Secretary of Defense (OSD) compose the largest component of the Basic Research Program—about 70 percent of total 6.1 funding. They represent the largest source of DoD research funding for universities, with the research carried out primarily through traditional single-investigator efforts. DRS programs also support research efforts performed by industry, government laboratories, nonprofit organizations, state and local governments, and Federally Funded Research and Development Centers (FFRDCs).

2.5.2 In-House Laboratory Independent Research

The primary goals of the ILIR program are to conduct quality basic research in support of laboratory missions and to provide a research environment conducive to the recruitment and retention of outstanding scientists and engineers. Capitalizing on special facilities and capabilities, the ILIR program typically conducts militarily relevant research that would not or could not be performed elsewhere. ILIR also provides high-level visibility to researchers achieving significant accomplishments. The annual DoD budget for ILIR activities is about $30 million.

2.5.3 University Research Initiative

The URI is a collection of special research, equipment, and eduction programs involving academic institutions. URI activities help to improve the quality of defense research carried out by universities and support the education of young scientists and engineers in disciplines critical to national defense needs. Specific aspects of the program are described below:

The *Multidisciplinary University Research Initiative* (MURI) supports teams of researchers investigating selected topics that intersect more than one traditional technical discipline. This multidisciplinary team approach complements the single-investigator university research funded by the service and defense agency DRS programs. For many complex problems, the multidisciplinary approach provides an effective means for accelerating research progress and applying the results to military programs. Total URI funding for multidisciplinary research was $117 million in FY96, including $13 million for new starts of interest to two or more services.

A typical successful MURI proposal includes not only joint activities involving different departments at an individual university, but also several universities working in collaboration. The MURI program has strongly supported the Strategic Research Objectives, and the subjects for research are both need-driven and opportunity-driven. Individual projects have typically been supported at $1–2 million per year over a 5-year period. Thus, prior-year obligations constitute the

Table 2-2. DoD Basic Research Funding ($ millions)

		FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
Services									
Army									
0601101A	In-House Laboratory Independent Research	14	14	15	16	17	17	18	18
0601102A	Defense Research Sciences	122	120	138	142	142	145	147	150
0601104A	University and Industry Research Centers	46	45	46	53	56	58	59	61
	Total Army 6.1	182	179	199	210	215	220	224	229
Navy									
0601152N	In-House Laboratory Independent Research	15	15	17	16	17	17	18	18
0601153N	Defense Research Sciences	361	352	384	393	403	413	423	432
	Total Navy 6.1	376	367	401	409	420	430	440	450
Air Force									
0601102F	Defense Research Sciences	216	211	227	230	236	241	247	255
Total Services		774	757	827	850	871	891	911	935
Defense Agencies									
Chemical and Biological Defense Program									
0601384BP	Chemical and Biological Defense Program	27	29	25	26	27	27	29	29
Office of Secretary of Defense									
0601101D	In-House Laboratory Independent Research	3	3	2	2	2	2	2	2
0601103D	University Research Initiatives	215	215	238	247	256	261	267	272
0601110D	Government/Industry Cooperative Research	0	0	15	16	16	16	16	17
	Total OSD 6.1	218	218	255	265	274	280	286	292
Defense Advanced Research Projects Agency									
0601101E	Defense Research Sciences	76	91	76	81	74	77	76	79
Total Defense Agencies		321	338	356	372	374	384	391	400
Total DoD		1,095	1,095	1,182	1,222	1,245	1,275	1,303	1,335

Note: Some columns do not add exactly to the totals due to rounding.

major part of the MURI budget. Research topics in the final stages of proposal evaluation in the current competition include:

- Cluster Engineered Materials
- Quasi-Optic Power Combining
- Design and Control of Smart Structures
- Dendritic Polymers for Next-Generation Functional Materials
- Air Plasma Ramparts for Tomorrow's Battlefield
- Cognitive Workload
- Intelligent Agents for Wireless Computing
- Advanced Acoustic Processors for Multiple DoD Applications
- Photonics for RF Systems
- Thermoelectric Materials for Cooling and Power Generation
- Semantic Consistency and Heterogeneous Information Systems.

Two additional projects will be funded from FY 1997 MURI funds in the Demining topic area, which was initiated in FY 1996.

The *Defense University Research Instrumentation Program* (DURIP) enables university researchers to purchase major research equipment (i.e., equipment costing $50,000 or more) that cannot be acquired with typical amounts provided by single-investigator awards. By providing support for major instruments that are critical to sustaining universities' long-term capabilities to perform cutting-edge research, DURIP complements investments made by service and defense agency DRS programs in more modest research instruments. DURIP provided $30 million for major research instrumentation in FY96.

The *Augmentation Awards for Science and Engineering Research Training* (AASERT) program increases the number of high-quality science and engineering graduate students that receive support through defense research for their degree-related research training. It also provides support for involving undergraduate students in defense research to stimulate their interest in advanced science or engineering studies. AASERT awards augment service and defense agency DRS awards, building on the research infrastructure established by those programs by supporting additional graduate students on research projects important to maintaining the vitality of the national science and engineering talent pool in defense-critical fields. In FY96, AASERT supported about 1,500 graduate and 300 undergraduate students.

National Defense Science and Engineering Graduate Fellowships are awarded for study and research leading to doctoral degrees in mathematical, physical, biological, ocean, and engineering sciences. These fellowships provide special recognition for some of the best and the brightest students in science and engineering, encouraging them to continue their academic studies and complete the research training needed to earn advanced degrees. These fellowships thus complement the incentives provided through research assistantships and traineeships. Approximately 300 fellows are being supported this year.

The *University Research Infrastructure Support Program* (URISP), in accordance with goals set by Congress to broaden the base of academic institutions participating in defense research, provided approximately $3 million in FY95 to institutions that had not traditionally received much DoD funding. URISP builds infrastructure at those institutions through awards for research, equipment, and student assistance.

The *DoD Experimental Program to Stimulate Competitive Research* (DEPSCoR) responds to congressional requirements to stimulate competitive research in states that have not traditionally been recipients of large federal research awards. In FY96, $20 million was appropriated to improve the capabilities of U.S. institutions of higher education in 18 states and Puerto Rico.

2.5.4 Other Programs

International programs provide a way for DoD to leverage technical expertise throughout the world by establishing links to various global scientific and academic institutions. As part of their basic research programs, the services maintain co-located offices in London and Tokyo to take advantage of the proximity to international centers of research excellence. The Air Force's European Office of Aerospace Research and Development; the Office of Naval Research, Europe (ONREUR); and the Army's European Research Office in London survey and report on promising developments in Europe, in countries that composed the former Soviet Union, in Africa, and in the Middle East. Similarly, the Asian Office of Aerospace Research and Development, the Office of Naval Research–Asia, and the Army Research Office–Far East examine scientific developments in the Pacific and Indian Ocean Rim countries. These overseas posts sponsor several kinds of activities, including promising seed projects at universities in foreign countries, international scientific conferences, and visits by eminent scientists to DoD laboratories and other research institutions to present seminars and lectures and to take extended sabbaticals. Often, these foreign seed efforts progress to the point where they can undergo transition to the appropriate service laboratory for further research. Annual service investment in this program is approximately $4 million by the Army, $7 million by the Air Force, and $5 million by the Navy. An example of what such programs have meant to DoD follows:

ONREUR conducted a small workshop in 1994 in Germany addressing Si–Ge on silicon (as a competitor to GaAs) for microwave applications. Major representatives from Europe and the United States included IBM, Daimler–Benz, and Siemens. Results of the workshop led to the formation of a special division within IBM (Analog Devices, Inc.) dedicated to the development and production of Si–Ge-based circuits for microwave products. These products include heterostructure bipolar transistors for power application in devices such as solid-state power amplifiers, which are primary components of a wide range of electronic warfare (EW) systems.

The *Focused Research Initiative* (FRI) has been a DoD research program involving collaborative efforts between academia, industry, and where appropriate, federal laboratories. Program activities were intended to amplify and accelerate research efforts in critical, high-payoff areas and to promote more rapid transitions from the basic research environment to applications important to warfighter effectiveness and system affordability. The work addressed five research topics:

- Virtual Environments for Training
- Cryoelectronics
- Wireless, Distributed Multimedia Communications Networks for the Digital Battlefield

- Photonics for Data Fusion Networks
- Low-Emission, High-Performance Gas Turbine Engines.

In the FY 1997 Omnibus Appropriations Conference Report, the FRI program was eliminated.

A new program is planned for 1998 and beyond. The *Government/Industry Cooperative Research* (GICR) program is intended to create a shared commitment between industry and government to capitalize on university-based research, education, and training in technologies of strategic importance and areas of mutual interest. University-hosted research centers created or supported under this program are intended to educate scientists and engineers in areas critical to the advancement of key technologies; provide a continuous infusion of new ideas and practices into university and industry settings through exchange of professional at all levels; and increase universities' awareness of industrial practices, motivations, and needs. Due to strong industry support, semiconductor electronics will be an early focus area for this program. Expanding long-term research in this and other key areas is of strategic importance to both government and industry, and the new knowledge base is expected to ultimately minimize the long-term vulnerability of key industries, support their long-term growth, infuse new ideas and approaches, and enhance national security.

3.0 STRATEGIC RESEARCH OBJECTIVES

The DoD Basic Research Program supports a broad range of diverse activities spanning numerous scientific disciplines. The results of these extensive fundamental research efforts help to provide a sound technical foundation for meeting both recognized current U.S. defense requirements and projected—but less-well-defined—future needs. To provide a sharper focus for certain research activities in areas considered to offer significant and comprehensive benefits to our national peacekeeping and warfighting capabilities, a number of Strategic Research Objectives have recently been established. Most of these objectives reflect the high-payoff potential of newer but maturing research fields recognized through the continual basic research review process. Others reflect the continuing importance of more established areas to achieving critical new capabilities for many types of military missions. These Strategic Research Objectives—and the associated research areas—are described in the following sections.

3.1 Biomimetics

Enable the development of novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.

Materials and structures of intricate complexity and exhibiting remarkable properties are found throughout the biological world. A unique feature of many biological systems is that their functionality derives from fabrication processes composed of several levels of self-assembly involving molecular clusters organized into structures of different length scales. The result is an optimized architecture tailored for specific applications through molecular, nanoscale, microscale, and macroscale levels that is unobtainable through conventional, equilibrium-based, synthetic fabrication methods.

The integration of the principles of biotechnology with materials science and engineering to create a new field called *biomimetics* establishes a conceptual approach for unraveling many of nature's secrets and exploiting them for a wide range of military applications. Biological system characteristics of interest include infrared signature visualization, exquisite sensing capabilities like sniffing and tasting that allow rapid and selective detection of only a few molecules of certain chemical species, echolocation that can detect and classify objects in noisy and cluttered environments, heightened agility and control capabilities in stressing environments, and protection of animals by shells and horns. Examples of possible products of biomimetics research include adhesives for emergency repairs and special operations, advanced sensors for detecting mines and biological/chemical warfare agents, and composite lightweight armor materials that integrate very hard and softer components to optimize strength and toughness. Advances in the field of biomimetics are also likely to contribute to accelerated production of designer vaccines and pharmaceuticals, novel gene therapies, and new detectors for environmental monitoring.

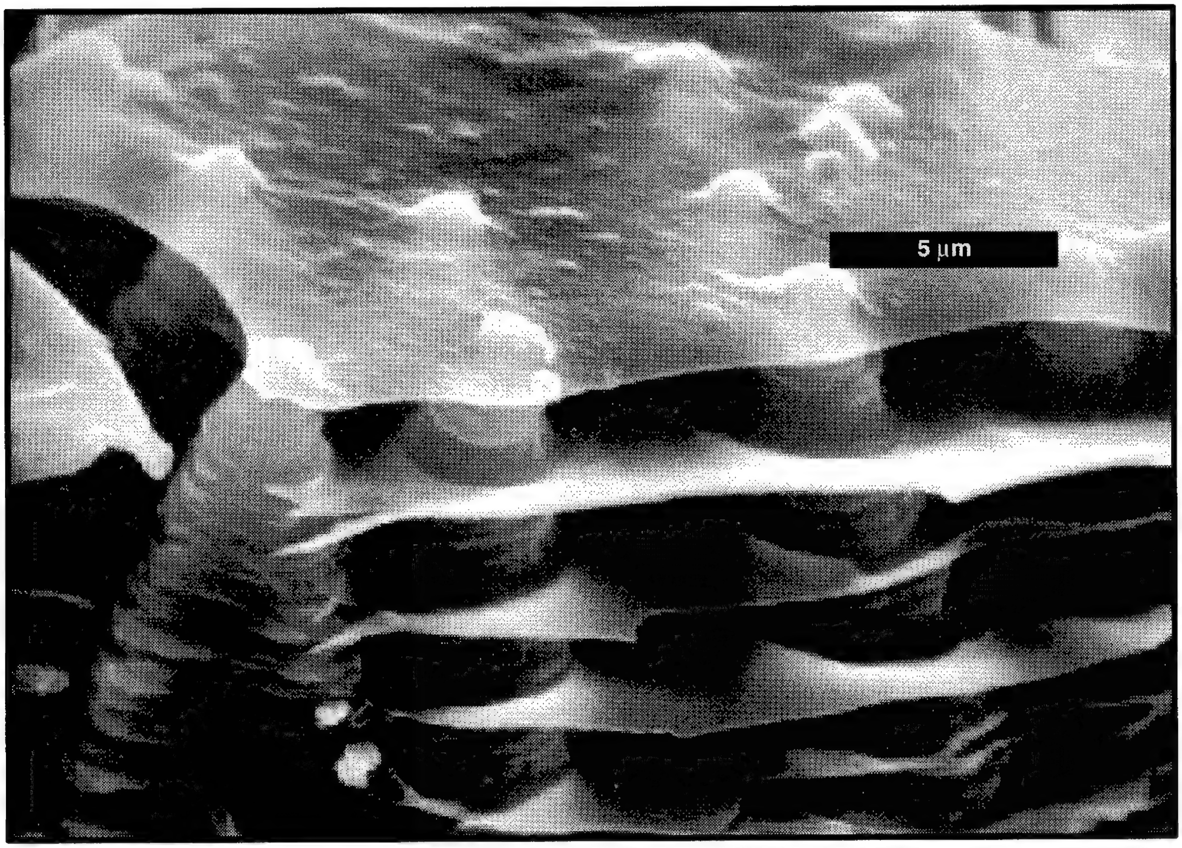


Figure 3–1. Growing Edge of Abalone Nacre. This image, recorded by researchers at the University of Washington using a scanning electron microscope, reveals the successive formation of aragonite (orthorhombic calcium carbonate) platelets by a nucleation and growth process that is controlled by the organic matrix (proteins and polysaccharides), seen in the image as self-assembled thin layers. The overall hybrid (organic/inorganic) nanocomposite results in an organized hierarchical structure with multifunctional physical properties. An improved understanding of such natural processes through biomimetics research will enable the development of advanced materials having unique properties (e.g., superior combinations of strength, stiffness, and toughness).

3.2 Nanoscience

Achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).

The ability to affordably fabricate structures at the nanometer scale will enable new approaches and processes for manufacturing novel, more reliable, lower cost, higher performance and more flexible electronic, magnetic, optical, and mechanical devices. Recognized applications of nanoscience include ultrasmall, highly parallel and fast computers with terabit nonvolatile random access memory and teraflop speed; image information processors; low-power personal communication devices; high-density information storage devices; lasers and detectors for weapons and countermeasures; optical (infrared, visible, ultraviolet) sensors for improved surveillance and targeting; integrated sensor suites for chemical and biological agent detection; catalysts for enhancing and controlling energetic reactions; synthesis of new compounds (e.g., narrow-bandgap materials

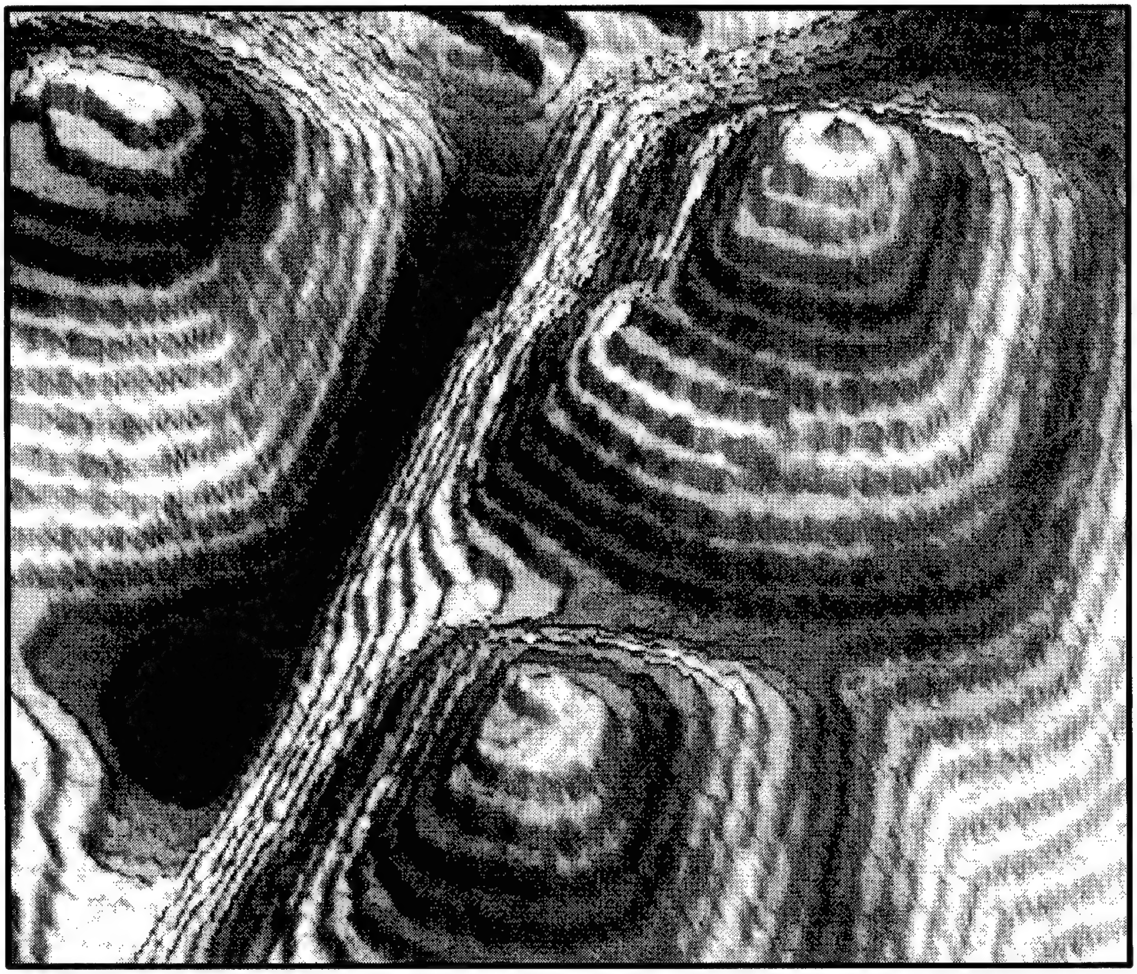


Figure 3–2. Spiral Growth of GaSb Film on GaAs at Nanoscale . This photomicrograph, obtained by research scientists at the Naval Research Laboratory (NRL) using a scanning tunneling microscope (STM), reveals spiral dislocations spontaneously formed on a 4-micron-thick film of GaSb grown on GaAs by molecular beam epitaxy. The image, with a field of view of ~1 micron x 1 micron, was acquired in situ following growth of the film. Atomic-scale control of surfaces and interfaces requires the combination of advanced materials growth techniques with in situ characterization. The ability to determine and control structures at the nanometer atomic scale will revolutionize next-generation electronic and optoelectronic devices, bringing new capabilities to DoD sensors and signal processing systems.

and nonlinear optical materials) for advanced electronic, magnetic, and optical sensors; and significant life-cycle cost reductions in many systems through failure remediation. These devices exploit exciting properties of nanoscale materials not predictable from macroscopic physical and chemical principles.

DoD support for nanoscience research is focused on creating new theoretical and experimental results involving atomic-scale imaging methods, sub-angstrom measurement techniques, and fabrication methods with atomic control that will provide reproducible material structures and novel devices. It also includes investigations of phenomena dominated by size effects or quantum effects. Scientific opportunities include understanding new phenomena in low-dimensional structures, nucleation and growth, self-organizing materials, site-specific reactions, elastic/plastic deformation, nanostructural materials, solid-fluid interfaces, and supramolecular materials.

3.3 Smart Structures

Demonstrate advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multi-element, deformable structures used in land, sea, and aerospace vehicles and systems.

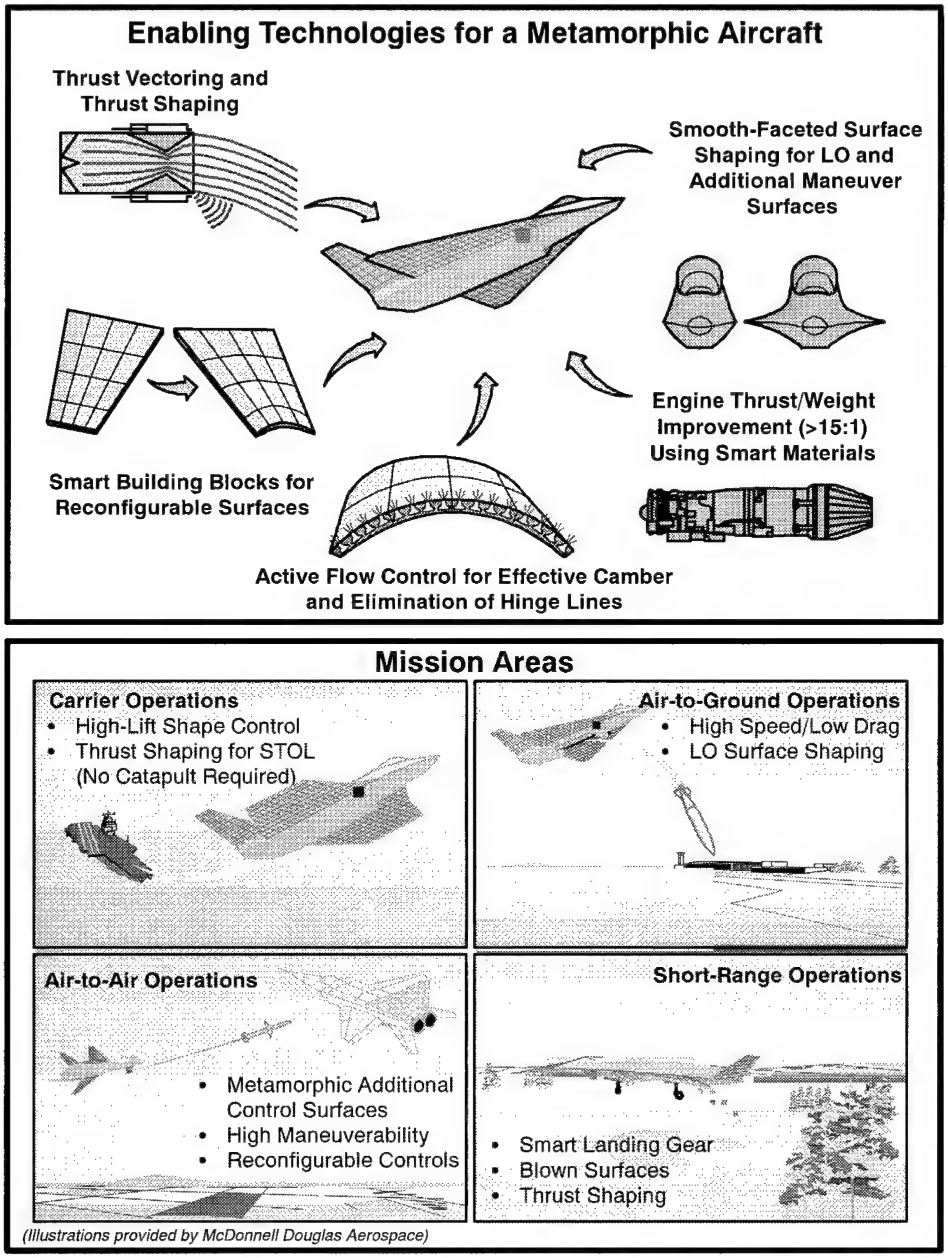


Figure 3–3. Enabling Technologies and Mission Areas for a Metamorphic Aircraft. Continuing research in a variety of smart structures and materials areas will enable the development of aircraft having unconventional and highly advanced performance characteristics of critical importance in executing many types of military missions. Relevant areas of interest and activity include coupled thermomechanical-electromagnetic nonlinear mechanics to describe system behavior, multifunctional structure-fabrication methods, reliable actuator materials and lightweight structural materials capable of physical and virtual shape change, sensor arrays for assessing the operational environment, and reconfigurable adaptive control systems to achieve real-time flight performance improvements.

Smart structures offer significant potential for expanding the effective operations envelope and improving certain critical operational characteristics for many DoD systems. Key characteristics of smart structures include integral or bonded sensors and actuators linked to a controller responsive to external stimuli to compensate for undesirable effects or to enhance overall system performance. To help realize the full potential of smart structures in military systems, the DoD Basic Research Program is supporting fundamental investigations that address active/passive structural damping techniques, advanced actuator concepts able to provide greater forces and displacements, embeddable and nonintrusive sensors, and smart actuator materials (e.g., electrostatic and piezoelectric materials, shape memory alloys, magnetorheological fluids). Important studies focused on new fabrication processes for actuators and sensors on the micron to millimeter scale, computationally accurate and efficient constitutive models for smart materials, advanced mathematical models for nonconservative and nonlinear structural and actuator response, robust hierarchical control with distributed sensors and actuators, and concurrent, integrated structural design and control methodologies are also being pursued.

Specific potential military applications of smart structures include shock isolation and machinery vibration and radiated noise control in submarines and surface ships; noise suppression and shape and flow control in submarine propulsors to reduce signature, improve maneuvering control, and eliminate cavitation; vibration control and stability-augmentation systems in fixed- and rotary-wing aircraft; vibration control and precision metrology of surveillance spacecraft systems; barrier structures providing improved protection against chemical and biological agents; structural damage detection and mitigation systems; more accurate rapid-fire weapon systems; fire-control and battle-damage identification, assessment, and control on surface ships; control of conformal antennas, phased arrays, and broadband spiral antenna systems; and smart skins for high-performance combat aircraft.

3.4 Mobile Wireless Communications

Provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, graphics, and video) from point to point, broadcast and multicast over distributed networks for heterogeneous C^3I systems.

Research in mobile wireless communications provides the technology for establishing and maintaining effective network communications on the move under the harsh and highly dynamic conditions expected on modern battlefields. Civil networks have a fixed structural component not possible in mobile military systems, and the military channel is more complex. Timely arrival of messages is highly critical in military networks, which can have no single points of failure and must be self-organizing to be survivable.

Research in mobile wireless communications is needed to dramatically improve the throughput, survivability, and security of complex mobile communication networks critical to the viability and success of future Force XXI mobile military operations. Research on high-frequency devices, sources, and waveguides and techniques such as quasi-optical combining can increase radio carrier frequencies beyond 20 gigahertz, enabling wider bandwidth channels. Research on smart antenna beamsteering with optical control and new methods of source, channel, and modulation coding enables increased capacity over limited bandwidth channels with lower power, thereby extending battery life and reducing probability of interception. Protocol engineering research provides the

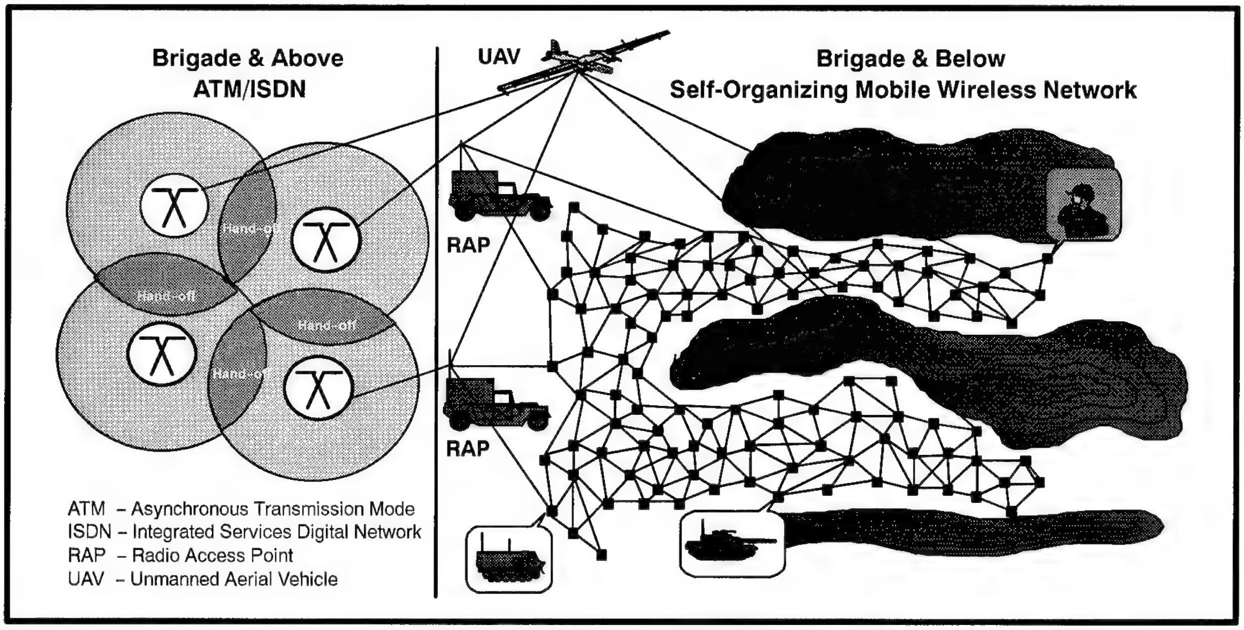


Figure 3-4. Mobile Wireless Communications. Seamless communication is the foundation for many of the capabilities required by the Army After Next (AAN) and described in the *Joint Warfighting Science and Technology Plan*. Commercial off-the-shelf equipment utilizing commercial standards such as ATM, ISDN, and TCP/IP (Transmission Control Protocol/Internet Protocol) is expected to meet the requirements for multimedia (voice, data, and video) services for fixed and transportable communications systems at the brigade level and above. In the 21st century, however, DoD must field a robust mobile wireless communication system capable of providing similar services to warfighters at the brigade level and below. The self-organizing networks and the ATM/ISDN networks are internetted through gateways at the radio access points (RAPs) and the unmanned aerial vehicles (UAVs). Relevant ongoing basic research is addressing the need to provide fully distributed, self-organizing, multimedia mobile wireless networks featuring mobile-to-mobile connectivity, smart antennas for spatial reuse of frequency channels, robust compression for wireless channels, and operation with minimum energy to extend battery life.

technology needed to integrate cable, satellite, and mobile wireless communications and for maintaining connectivity, routing, and quality of service for multimedia communications in highly dynamic networks. Advances in mobile wireless communications will significantly increase the capacity of the Defense Information Infrastructure.

3.5 Intelligent Systems

Enable the development of advanced systems able to sense, analyze, learn, adapt, and function effectively in changing or hostile environments until completing assigned missions or functions.

Intelligent systems offer exciting new possibilities for conducting many types of military operations, ranging from reconnaissance and surveillance activities to a variety of specialized combat operations. Intelligent systems typically consist of a dynamic network of agents interconnected via spatial and communications links that operate in uncertain and dynamically changing environments using decentralized or distributed input and under localized goals that may change over time. The agents may be people, information sources, or automated systems such as robots, software, and computing modules.

Intelligent systems must be capable of gathering relevant, available information about their environment, analyzing its significance in terms of assigned missions/functions, and defining the

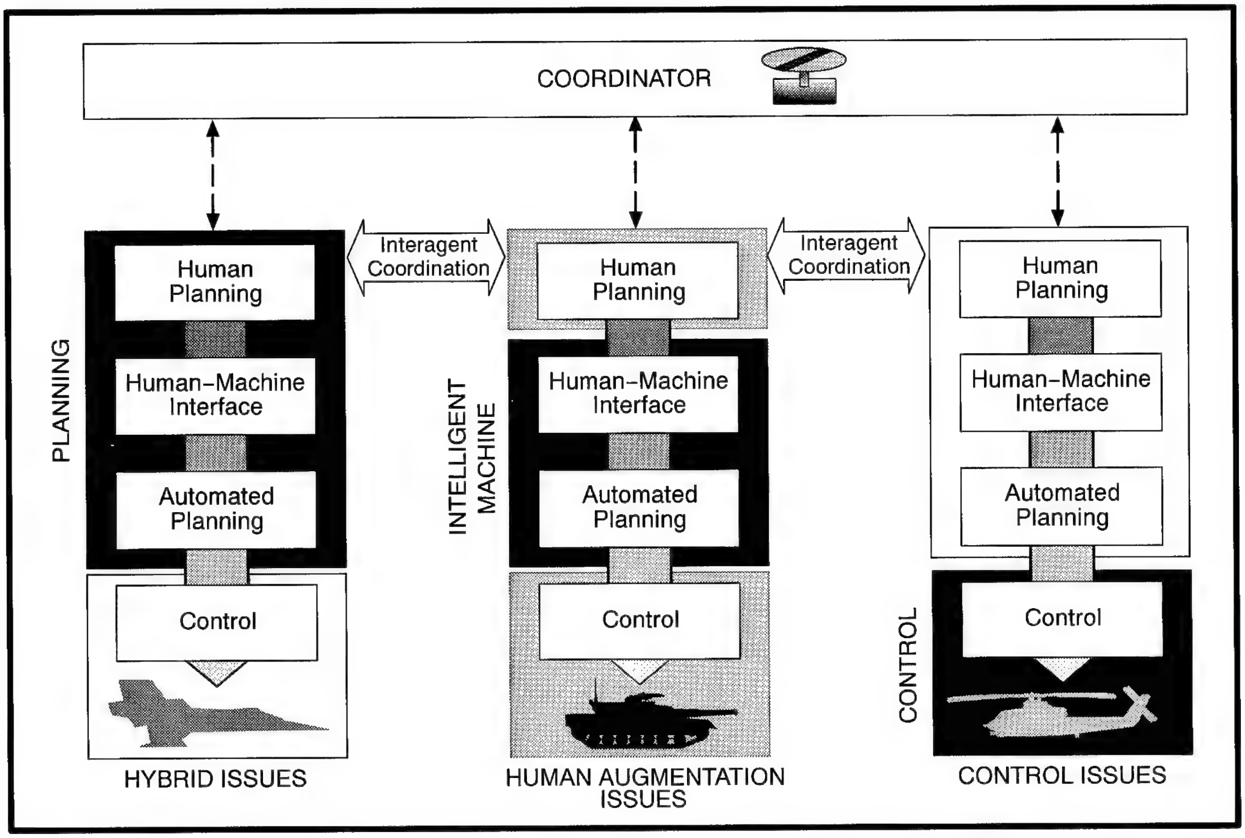


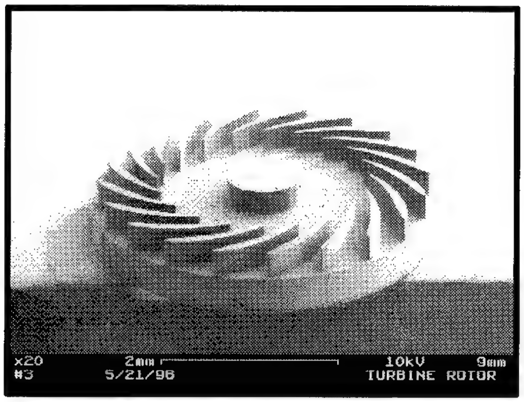
Figure 3-5. Intelligent Digital Battlefield Architecture. Intelligent systems research includes activities pertinent to the performance of hybrid systems, human intelligence augmentation, and low-level control. Hybrid system research will lead to robust design of advanced architectures for multi-agent/distributed control. Research involving representation and learning in the presence of uncertainties or incomplete information (soft computing: neural networks, fuzzy logic, Bayesian decision theory, etc.) will provide tools for intelligence augmentation of human-centered decision systems.

most appropriate course of action consistent with programmed decision logic. Achieving these objectives requires integration of significant scientific and technological advances in many diverse fields: electronics, physics, mathematics, materials science, biology, computer science, cognitive and neural sciences, control theory and mechanisms, and electrical and systems engineering. Critical areas of research being pursued include the design of multi-agent systems, representation of hierarchical perception systems, advanced models for learning and adaptation, development of effective frameworks for representing and reasoning with uncertainty, and new computational paradigms for accommodating imprecision in human-centered systems. The numerous potential military applications of intelligent systems include unmanned vehicles (air, ground, and underwater types), smart weapons, real-time command and control systems for future battlefields, and chemical/biological defense systems.

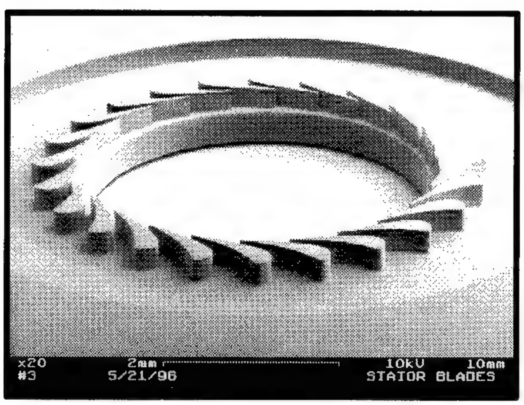
3.6 Compact Power Sources

Achieve significant improvements in the performance (power and energy density, operating temperature, reliability, and safety) of compact power sources through fundamental advances relevant to current technologies (e.g., batteries and fuel cells) and the identification and exploitation of new concepts.

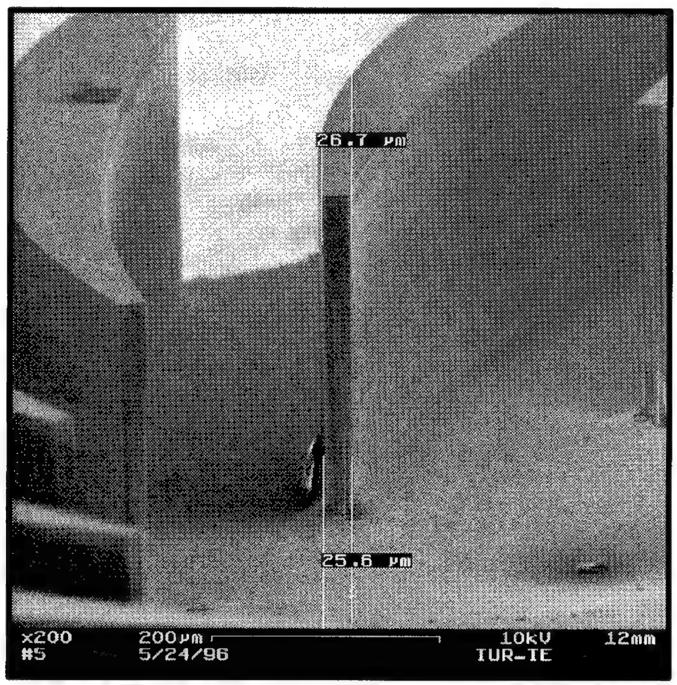
Efficient, long-life, durable, and quiet compact power sources are a critical requirement for numerous defense applications, including electronics, communications, heating and cooling, weapons, and propulsion systems. To improve battery performance, breakthroughs in anode, cathode, and supercapacitor material are being sought, in conjunction with investigations of novel manufacturing methods. For fuel cells, which meet long-mission requirements not possible with battery technology, increased emphasis is being given to fuel issues and the development of new membrane materials. For both batteries and fuel cells, new diagnostic tools and advanced modeling capabilities are also needed to understand the structural and dynamic properties of working cells. New compact power concepts being considered include thermophotovoltaics and micro gas turbine generators based on microelectromechanical systems (MEMS) technology that could provide very high power-to-weight ratios (e.g., 100 watts per gram). Specific applications of advanced compact power sources include lightweight night vision equipment, portable communications systems, satellites, equipment and soldier status-monitoring devices, command and control hardware, smart weapons, surveillance devices, and environmental monitoring/control systems.



Rotor



Stator



Rotor Trailing Edge Definition

Figure 3-6. Microfabricated Turbine Components for a Micro Gas Turbine Generator. Research focused on a variety of issues involving materials, thermal management, bearing design, high-aspect-ratio etching, microscale combustion, turbomachinery, and generator design is being carried out at MIT under DoD sponsorship. Microfabrication of refractory ceramics holds the promise of power densities approaching those of full-size turbomachinery while achieving the low costs associated with microfabrication. The figure shows one of the first power turbine rotors and stators etched in silicon; the walls remain vertical to within 1 micron over the entire etching depth of 200 microns.

3.7 Summary, Funding, and Specific Goals

Consideration of many projected research results for these areas relative to numerous specific technology objectives cited in the *Defense Technology Area Plan* (DTAP) has served to underscore the pervasive importance of the Strategic Research Objectives to improving U.S. defense capabilities applicable to a wide range of military systems and operations. In managing the Basic Research Program, special attention is being given to these areas and objectives to help ensure that their great potential can be realized through subsequent technology and system development efforts. Identification of additional such areas and objectives will be sought in continuing reviews of basic research activities. Funding data for basic research work supporting the Strategic Research Objectives is provided in Table 3–1. Representative specific research goals associated with the Strategic Research Objectives described above are provided in Table 3–2.

Table 3–1. Funding Profiles for Basic Research Supporting Strategic Research Objectives ($ millions)

	FY96	FY97	FY98
Biomimetics	8.0	10.0	10.0
Nanoscience	28.7	24.0	22.9
Smart Structures	9.8	8.7	7.1
Mobile Wireless Communications	11.8	10.8	11.0
Intelligent Systems	18.5	18.5	19.0
Compact Power Sources	9.0	9.5	10.0
Totals	85.8	81.5	80.0

Table 3–2. Representative Specific Basic Research Goals Associated With Strategic Research Objectives

2000	2005	2010
	Biomimetics	
Demonstrate advanced design principles for high-performance composites Fabricate/evaluate new advanced armor and semi/super-conductor materials based on biomimetic principles Demonstrate biologically derived advanced materials for optical modulators	Demonstrate advanced adhesives for use in adverse environments Utilize principles of metabolic design for synthesis of advanced materials Fabricate porous lightweight and resilient structural materials with novel properties and uses Demonstrate new materials for improved uncooled IR detectors	Demonstrate utility of biochemical transducers for MEMS devices Achieve decontamination of chemical agents using biomimetic catalysts Demonstrate principles of stealth propulsion without motors or gears Demonstrate new sensors based on the olfactory system
	Nanoscience	
Adapt scanning probe technology to high-sensitivity sensing Demonstrate multilayer film growth and self-assembled 3-D structures with atomic control Demonstrate robust, ultrathin insulators for quantum tunneling in silicon Achieve enhanced performance of propellants and explosives through nanoparticle surface chemistry	Utilize nanostructure elements for terabit computer memory Demonstrate cellular network concepts with single electron devices Sense single biomolecules for medical and CBW diagnosis Demonstrate a quantum phase transistor	Demonstrate advanced electronic devices based on single atoms or molecules Lower life-cycle costs by 10% through in situ detection of material failures on the nanometer scale Design nanomaterials by atomic manipulation Define capabilities of solid-state devices for quantum computing

Table 3–2. Representative Specific Basic Research Goals Associated With Strategic Research Objectives (continued)

2000	2005	2010
	Smart Structures	
Demonstrate new, reliable, cost-effective composite smart materials for low- and high-frequency structural control applications Achieve up to 40-dB reduction in vibration using embedded shaped sensors in rotorcraft box beams	Demonstrate up to 60-dB vibration reduction using shaped sensors and adaptive control algorithms Achieve MEMS wireless communications in a rotorcraft flight structure Demonstrate new impact-energy-dissipating smart materials	Demonstrate a low-cost, self-tuning vibration damping patch with integrated power and sensing microprocessors Demonstrate addressable fiber optic sensor arrays for damage detection in composite structures
	Mobile Wireless Communications	
Demonstrate wireless low-frame-rate/SNR video capabilities Achieve a twofold increase in the throughput of wireless systems Demonstrate scaleable data-compression methods adaptable to variable bandwidths using multi-resolution methods	Demonstrate improved video capabilities in wireless multimedia systems Demonstrate new methods for analyzing security properties of wireless networks to enhance intersystem compatibility Achieve Internet (ATM) compatibility between different protocols	Achieve full video capability in wireless multimedia systems Demonstrate adaptive antennas for battlefield communications Enable development of advanced minimum energy systems Demonstrate fully distributed networks (mobile-to-mobile communication)
	Intelligent Systems	
Establish fundamental roles played by hierarchical organization, compositionality, and learning in IS design Define/characterize simulated battlefield environments for testing IS methodologies Demonstrate intelligence augmentation of human-centered systems, with emphasis on cognitive issues	Establish a framework for integrating high- and low-level aspects of intelligent systems Exploit framework in devising next-generation control algorithms and designing prototype systems (e.g., that have integrated vision/control systems) Define/characterize integration of intelligent systems into larger network of systems (e.g., C^3I)	Achieve new understanding of learning styles in the human brain relevant to the design of intelligent systems Demonstrate useful performance characteristics of fully autonomous intelligent systems Demonstrate advanced sensor/control capabilities for fully autonomous intelligent systems
	Compact Power Sources	
Achieve single-ion conduction in polymer electrolytes for enhanced battery performance Demonstrate higher performance ultracapacitor, battery, and fuel cell catalyst materials Demonstrate hydrogen-fueled MEMS-based microturbines	Achieve 2x increases in the power and energy density of rechargeable lithium batteries Demonstrate advanced microturbine generators with efficient power electronics (>10W/cm^3) Demonstrate quiet liquid-fueled thermophotovoltaic power sources (250 W/kg)	Demonstrate a MEMS-based closed-loop thermal energy system Demonstrate a compact 150-W fuel cell that operates on logistics fuels at moderate temperature Demonstrate liquid-fueled microturbine generators with efficient power electronics (>100W/cm^3)

4.0 BASIC RESEARCH AREAS

The great majority of the scientific research work comprising the DoD Basic Research Program involves twelve technical disciplines:

- Physics
- Chemistry
- Mathematics
- Computer Science
- Electronics
- Materials Science
- Mechanics
- Terrestrial Sciences
- Ocean Sciences
- Atmospheric and Space Sciences
- Biological Sciences
- Cognitive and Neural Science.

Coordinated tri-service oversight for research in these areas is provided by the Scientific Planning Groups (SPGs), as noted in Section 2.3. Selected details regarding specific thrusts within each discipline, budget information, commonality and divergence of service interests, and representative basic research goals in each area are provided in the following sections.

4.1 Physics

Physics research is directed toward the development and understanding of fundamental principles that determine the operational bounds of many different types of military equipment. The Physics SPG plans and executes a well-integrated, forward-looking Basic Research Program that supports service-specific technologies in the areas of weapons, weapon platforms, sensors, communications, navigation, surveillance, countermeasures, and information processing. As such, the Physics SPG crosses all four elements of the *Joint Warfighting Science and Technology Plan* by supporting, for example, the following S&T contributions to military needs: ground, sea, air, and space sensor research; sensor improvement research; advanced radiation sources; littoral mine detection; precision strike (targeting); surveillance; guidance and control; lethality technologies; high-power microwaves (HPM), which can be used to neutralize, disable, disorient, or confuse without lasting effects; atomic clock improvements, which in turn affect GPS performance improvements; deployable unattended sensors; and techniques for detecting and evaluating the existence of manufacturing capabilities for weapons of mass destruction (WMD).

A number of research activities are under way in other government agencies that address service-specific needs. These programs are well known to DoD Basic Research Program managers and are used to leverage DoD investments. The definition of service-specific research in Physics clearly follows lines of respective mission applications. The Army focuses on soldier platforms, the Navy on surface ship and underwater applications, and the Air Force on atmospheric and space flight applications. The need for lightweight, small devices for airborne platforms by the Air Force has resulted in a program to develop visible laser technology for possible use in optical countermeasures. The Army has an active program in displays and smart focal planes to support the combat soldier, along with uncooled detectors to lighten the soldier's load. Research for mobile power sources for the soldier and for land vehicles is also being conducted by the Army. The Navy continues to pursue research to develop blue/green lasers for undersea communications and mine detection. In addition,

Navy research in acoustics is focused on physical acoustics and underwater acoustics involving propagation and transducers. Application of nonlinear control to signal discrimination in ocean acoustics is also of interest to the Navy. The Air Force has an active program in optical compensation for the imaging of space objects through the atmosphere.

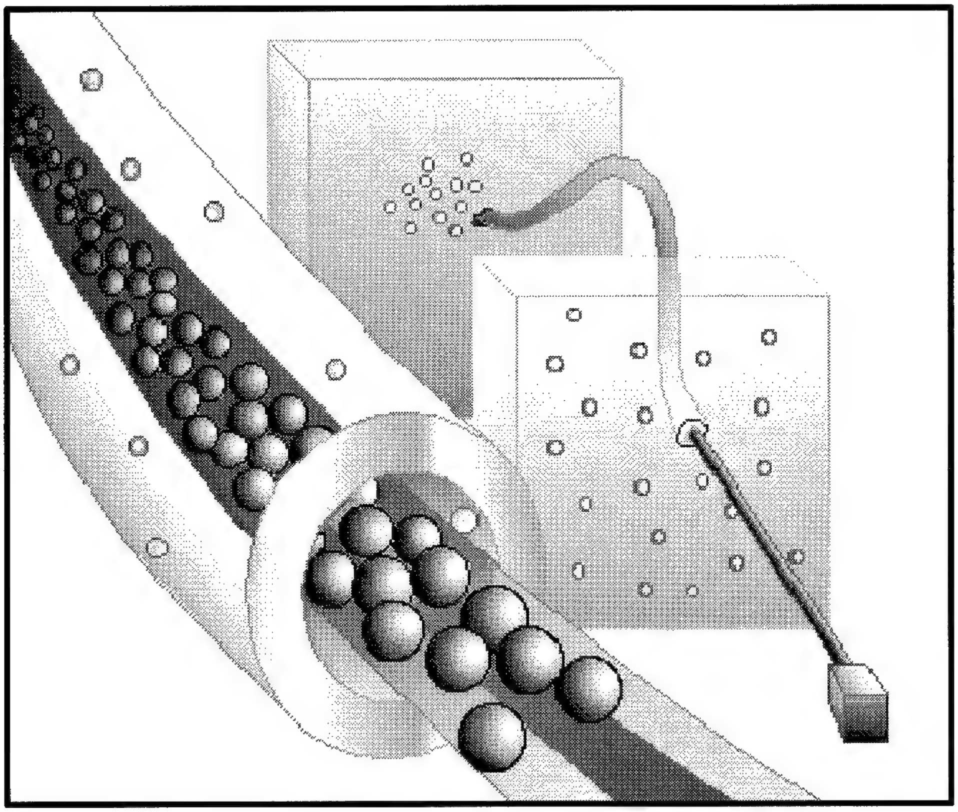


Figure 4–1. Hollow Fiber Optic Technology. Physics is the discipline that discovered the atom. In recent years, single atoms have been imaged and manipulated. This figure shows a hollow fiber optic technology called an atom hose, under study at the University of Colorado, which is used to transport atoms to an "atom interferometer." Atoms are kept efficiently moving through the center of the hose using laser light. Employing the quantum mechanical properties of matter, physicists are performing interference experiments with single atoms. The atom can pass through two separate routes in an atom interferometer and interfere with itself. This type of experiment was traditionally performed only with light. Because an atom's DeBroglie wavelength is very small compared to that of light from radiation sources, the sensitivity of atom interferometry is greatly enhanced over that of a traditional interferometer. In addition, an atom, unlike a photon, can respond to electric, magnetic, and gravitational forces. For example, an atom interferometer is theoretically capable of locating underground tunnels via detection of ground mass variations.

Within DoD, Physics research supports the defense strategic investment specific technology priority in sensors and the two generic priorities of dual use and affordability. Physics research falls into four general subareas: radiation, matter and materials, energetic processes, and target acquisition. The approaches to these four subareas are included in their descriptions below.

Radiation: *Research in this area runs the gamut from the x-ray to microwave regimes. Advanced radiation sources are needed to satisfy DoD requirements for C^3I, radar, sensors, electronic warfare (EW), directed energy weapons (DEWs), and other systems.* In addition to radiation sources, this area involves the propagation of radiation and detection of objects using radiation in different military environments. Research thrusts in this area include novel (e.g., ultraviolet) and blue/green lasers, high-power microwaves, uncooled detectors, nonlinear optics, and optical compensation.

Matter and Materials: *Matter and materials research ranges from nanoscale (atomic-scale systems) to macroscale (high-T_c superconductor materials) characteristics that impact many DoD systems, such as Global Positioning System (GPS) performance improvement (atom traps and their impact on atomic clocks) and low observables (e.g., bandgap engineered materials).* Accordingly, the area involves elements in the plasma (the fourth state of matter), optical, and atomic arenas. For example, advances in the scientific understanding of plasma processing will in turn affect the microelectronics fabrication area, which will enable smaller feature sizes (submicron) in semiconductor wafers. Technology requirements for future DoD electronics systems are introducing increasingly stressing requirements, which can only be met by an increased scientific understanding in the processing area.

Energetic Processes: *Many DoD systems are impacted by research in energetic processes because they have critical power-generation and high-voltage requirements.* This area involves elements in high voltage, plasmas, power generation, and energy storage. Representative research thrusts include mobile power sources, thermophotovoltaics, compact accelerators, pulsed power, ultra-high-field physics, and plasmas (neutral and nonneutral, collisionless and collisional). In addition, neutral plasma effects can provide stealthy conditions for DoD aircraft and satellites.

Target Acquisition: *The survivability of DoD platforms (ships, tanks, aircraft) and systems (C^3I satellites, etc.) depends on advances in the area of target acquisition.* The area involves an element within the oceanographic and atmospheric arena. Research thrusts in this area are focused on detection means (devices) and displays. For example, in order for the Army to "see" tanks through the fog of battle, advances are needed in imaging science. The Navy performs research in nonlinear dynamics and acoustic and nonacoustic wave propagation (e.g., use of extremely low frequency/very low frequency (ELF/VLF)) to counter the threat of submarines and mines in littoral regions. Moreover, the Air Force must image space objects through the atmosphere.

Budget information for Physics research is provided in Table 4.1–1. Table 4.1–2 provides an outline of service-specific interests and commonality in this research area. Representative basic research goals for Physics in the near and far term are given in Table 4.1–3.

Table 4.1–1. Basic Research Funding for Physics ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601102A	Army	5.6	8.3	7.5
PE 0601104A	Army	0.0	2.0	2.0
PE 0601152N	Navy	3.2	3.1	3.4
PE 0601153N	Navy	34.9	33.9	37.0
PE 0601102F	Air Force	22.0	20.6	21.6
Total		65.7	67.9	71.5

* Program Element names listed in Table 2–2.

Table 4.1–2. Service-Specific Interests and Commonality in Physics

Subarea	Army	Navy	Air Force
Radiation Sources Detection Propagation	Uncooled detectors Sub-mmw research	X-ray sources Blue-green lasers Quantum noise	Optical compensation Microwave sources
	Areas of Common Interest: optical image processing (A, AF); ultra-fast EO (A, N, AF); novel lasers (A, N, AF); optical diagnostics and testing (A, N, AF); high-power microwaves (N, AF); nonlinear optics (A, N, AF)		
Matter and Materials Plasma Optical Atomic	Atomic-scale systems Low observables Soldier displays	Physical acoustics Energetic and nonlinear IR materials	Visible lasers Semiconductor lasers
	Areas of Common Interest: character of plasma processing (A, N); ferroelectrics (A, N); nanostructures (A, N, AF); surfaces and interfaces (A, AF); atomic interferometry (A, N, AF); high-T_c superconductors (N, AF); atom traps (N, AF); computational physics (A, N, AF)		
Energetic Processes High voltage Plasmas Power generation	Mobile power sources Thermophotovoltaics	Compact accelerators Pulsed-power research Ultra-high-field physics	Neutral plasma effects
		Areas of Common Interest: nonneutral plasmas (N, AF); collective phenomena (N, AF)	
Target Acquisition Oceanographic and atmospheric	Smart focal plane arrays Foundations of image science	Nonlinear acoustic phenomena Sound/fluid/structure interactions Active and passive sonar Long-range acoustic propagation	Atmospheric discharges
	Areas of Common Interest: ionosphere modification and propagation (N, AF); nonlinear dynamics (A, N, AF)		

Table 4.1-3. Representative Basic Research Goals in Physics

Area of Military Impact	Relevant DTAP(s)	Year 2000	2005	2010
		Radiation		
Imaging of GEO satellites	Sensors, Electronics, and Battlespace Environment	Atmospheric compensation	Hyperspectral image processing	Centimeter-scale resolution
Man-portable (head-mounted) thermal imagers	Sensors, Electronics, and Battlespace Environment	Background-limited detection	Affordable detector arrays	Man-integrated intelligent display
Optical mine detection	Sensors, Electronics, and Battlespace Environment	High-efficiency coherent sources	Single-pulse imaging capability	3-D imaging capability
		Matter and Materials		
Low observables	Weapons Materials/Processes	Ferroelectric layered structures	Photonic bandgap engineered materials	Actively controlled absorbing materials
Optical countermeasures	Weapons Sensors, Electronics, and Battlespace Environment	Active eye protection	Efficient visible lasers	Optically based RF jammers
Precision targeting and GPS performance improvement	Materials/Processes	Compact optical clock	Atom trap lattices	Tabletop field isolated atom traps
		Energetic Processes		
Mobile power systems	Human Systems Weapons	Disposable fuel cell	Man-portable thermophotovoltaics	Logistically compatible fuel cell
EW and DEW systems	Weapons	Plasma stealth	Compact laser-plasma accelerators Agile plasma mirror	Compact reflex triodes Air Plasmas
		Target Acquisition		
Automatic target recognition (ATR)	Information Systems Technology	Algorithm performance	Quantification of scene clutter	Theory of image complexity
Littoral ASW	Sensors, Electronics, and Battlespace Environment	Nonlinear signal processing for detection/ classification	Acoustic imaging in shallow water Ray chaos models	Acoustic holography

4.2 Chemistry

Chemistry research directly affects a wide range of critical DoD systems and missions. Such research is central to developing advanced materials for specific DoD applications and to developing suitable processes for producing these materials in cost-effective ways. Examples are developing materials for protection against chemical weapons, producing novel propellants and power sources, developing processes to protect materials against corrosion, and developing methods to demilitarize munitions. The ability to tailor material properties to meet DoD needs arises from an understanding at the molecular level of the relationships between structure and properties. This understanding of molecular processes and properties established through Chemistry research enables the design of components for military systems that exploit these properties for optimal performance.

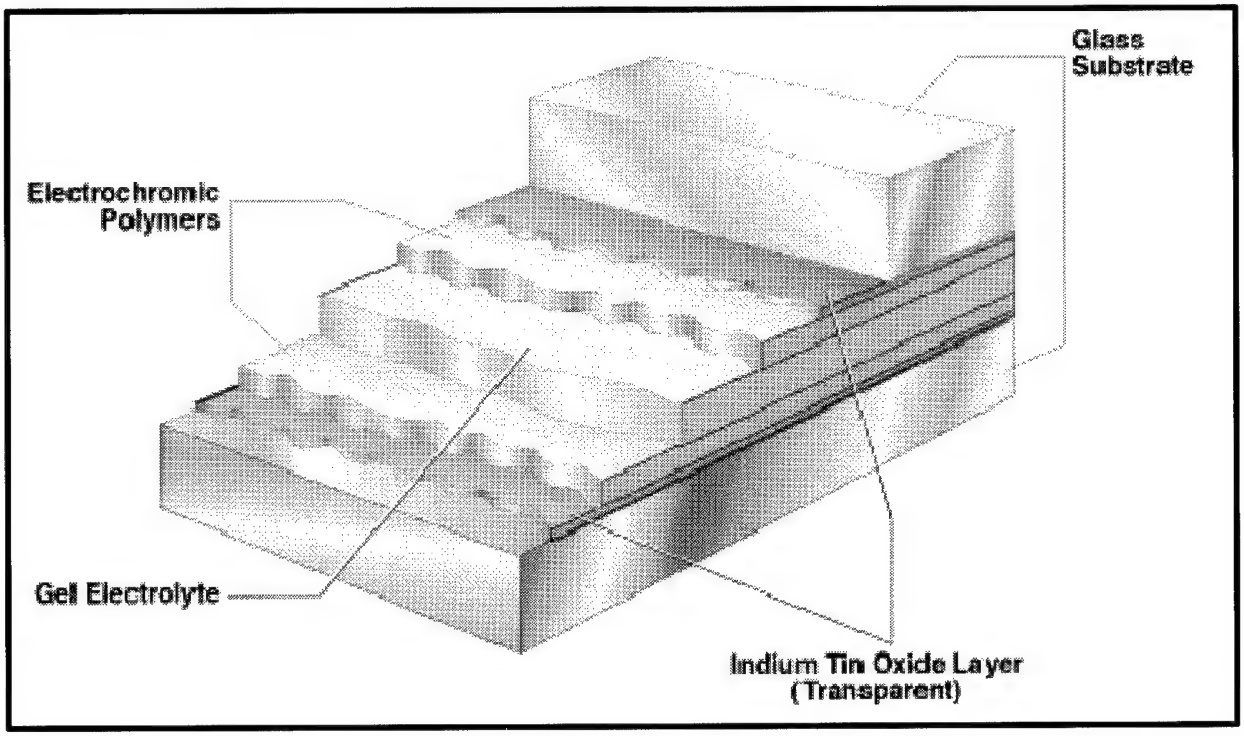


Figure 4-2. Rapid Control of Transparency Achieved Through Electrochromic Polymers. Special polymers have been developed having molecular structures that can be chemically tailored so that the optical transmission can be rapidly controlled by an applied voltage. Complementary pairs of electrochromic polymers are combined to produce transparent and colored states. The transmission of structures containing these materials can be varied over wide ranges in a fraction of a second. One application of these electrochromic polymers is to control the transparency of aircraft canopies.

Responsibilities for topics within the Chemistry area of the Basic Research Program are distributed in accordance with service mission considerations. These coordinated programs retain the responsiveness to pursue new scientific developments and service needs. The Army continues to emphasize systems related to chemical and biological defense (permeability, reactive and catalytic polymers) and to elastomers because of the heavy use of rubbery components in land vehicles. Important Navy areas of concentration include special considerations due to the marine environment, adhesion and surface properties relating to ship antifouling coatings, electronic and optical materials and properties, and transducer and display applications. The Air Force emphasizes

materials that maintain their integrity in extreme environments, corrosion chemistry related to aging aircraft, advanced ceramic precursors for high-temperature engine applications, chemical lasers, and processes that affect operations in the atmosphere and in space. DoD requirements for power sources are currently covered by extensive Army and Navy efforts and their associated DARPA programs. Topics of common interest continue to be: energetic materials, led by the Army (there is no civilian effort on which to depend); optical polymers for rapidly disseminating and displaying information to the warfighter; and very exciting forefront topics where specific applications remain the subject of speculation (e.g., nanostructures, biomimetics).

Chemistry research within the DoD Basic Research Program is divided into two major subareas:

Materials Chemistry: *Advanced materials play a key role in numerous DoD systems having widespread applications. Chemistry research focuses on the molecular design and synthesis of materials with properties that can be tailored to specific DoD requirements.* Structure/property relationships are determined to enable the design of optimal material systems. In addition to the applications cited above, other widespread applications of Chemistry research include developing materials for marine and aerospace environments, strong and lightweight composite materials, electronic materials, semiconductors, superconductors, and barriers for chemical and biological weapons.

Processes: *The ability to control the interaction between materials and their environments can be exploited for many DoD applications. Controlling friction and adhesion, corrosion, signatures, and the fate and transport of chemicals are some of the areas where this work impacts DoD operations.* Molecular processes are also being exploited to develop compact fuel cells as portable, clean power sources; to develop chemical lasers for directed-energy weapons; to control ignition and detonation of munitions; and to store energy in propellants.

Army research on polymers and elastomers continues to develop materials with properties tailored for chemical and biological defense needs. Ongoing research is addressing the destruction of munitions and the catalytic oxidation and hydrolysis of chemical agents and toxins, as well as techniques for detecting trace amounts of chemical hazards. The Army has consolidated its efforts in the area of highly branched dendritic molecules and will lead the services in that area. Research on hydrogen, methanol, and liquid hydrocarbon fuel cells continues as a growing area led by the Army. The Navy continues its leadership in electrode interfaces and materials expected to continue to eventual development of medium- to large-scale energy conversion systems. The Navy leads work on semiconductors that involves the development of site-selective dopants and deposition processes for improved optoelectronics and transistors. Research in tribology is developing an understanding of the role of surface chemistry in friction and wear, for example, to support synthesis of tailored lubricants. The Air Force continues to develop new materials synthesis methods, including processes for producing ceramics, composites, and sol gels able to operate in extreme environments. Novel work on inorganic polymers holds promise of a new class of versatile materials. Current work is also aimed at providing opportunities for IR-detection countermeasures. Air Force work to understand, detect, and prevent corrosion of aircraft is increasing. Common efforts within the SPG in chemical synthesis address energetic materials, supramolecular chemistry for biomimetics and detection, and optical materials. Research on optical polymers for information processing applications is continuing to make great progress important to meeting many DoD needs.

Budget information for Chemistry research is provided in Table 4.2–1. Table 4.2–2 provides an outline of service-specific interests and commonality in this area. Representative basic research goals in Chemistry are cited in Table 4.2–3.

Table 4.2–1. Basic Research Funding for Chemistry ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	1.6	1.9	2.1
PE 0601102A	Army	5.2	5.6	6.3
PE 0601152N	Navy	0.8	0.8	0.9
PE 0601153N	Navy	25.4	25.4	27.7
PE 0601102F	Air Force	28.3	28.7	33.3
Total		61.3	62.4	70.3

* Program Element names listed in Table 2–2.

Table 4.2–2. Service-Specific Interests and Commonality in Chemistry

Subarea	Army	Navy	Air Force
Materials Chemistry Theory Molecular design Synthesis and properties of compounds	Catalysts (CBW) Elastomers Reactive polymers (CBW) Barrier materials Dendritic molecules	Acoustic materials Electronics materials Inorganic semiconductors and superconductors Minimally adhesive surface IR materials Organic composites	Organic superconductors Biotechnology/biosynthesis Ceramic materials, coatings, composites
	Areas of Common Interest: biomimetics (N, AF); nanostructures (A, N, AF); energetic materials (A, N, AF); power sources (A, N, AF); polymers with delocalized electronic states (N, AF); lubricants (N, AF)		
Processes Atomic and molecular energy transfer Transport phenomena Reactions Changes of state	Reactions in SCF Combustion (DEMIL) CBW detection Organized assemblies Decontamination Diffusion/transport in polymers Energetic ignition/detonation	Biomimetic catalysis (CBW) Combustion/conflagration in fuels Adhesion Thin-film growth processes	Chemical lasers Atmospheric and space signatures and backgrounds Processing (ceramics, polymers, sol gels) Biodegradation Environmental processes
	Areas of Common Interest: power sources (A, N, AF); dynamics (A, N, AF); biocorrosion (N, AF); chemistry of corrosion and degradation (A, N, AF); tribochemistry (A, N, AF)		

Table 4.2–3. Representative Basic Research Goals in Chemistry

Area of Military Impact	Relevant DTAP(s)	Year 2000	2005	2010
Materials Chemistry				
Chemical/biological defense	Chemical/Biological Defense and Nuclear Biomedical	Point biodetectors Equipment for decontamination High-temperature catalysts General percolation model	Remote sensors for known biothreats Wide-area decontamination Room-temperature catalysts Fabric percolation model	Sensors for unknown biothreats Satellite-based sensors Active uniform barrier Smart coatings to destroy chem/bio agents
Information processing and displays	Sensors, Electronics, and Battlespace Environment Information Systems Technology	Efficient blue optoelectronics Higher speed microwave/mm wave devices Molecular transistors	Full-color, low-power optoelectronics Chemically deposited phosphors for FED Atomic control of deposition/doping	SAM technology for semiconductor processing
Communications and information transfer	Information Systems Technology Sensors, Electronics, and Battlespace Environment	Thermally stable NLO polymers	Polymer modulators Intrinsically polar polymers	All polymer display Ultrafast information processing
Ordnance and propulsion	Weapons Space Platforms	Energetic additives for liquid-fueled rockets Environmentally benign and lower toxicity propellants	Process-efficient motor formulations Chlorine-free liquid oxidizers	Cryogenic solid hybrid propellants Chlorine-free solid oxidizers
Processes				
Power sources for soldiers, military vehicles, and devices	Ground and Sea Vehicles Human Systems Sensors, Electronics, and Battlespace Environment	New processing technologies for porous electrodes Hydrogen sources for man-portable fuel cells Prototype direct methanol and high-temperature liquid hydrocarbon fuel cells	Control neutral transport in PEM fuel-cell membranes Cooling for hydrogen fuel cells Fielded methanol fuel cells Low-temperature liquid hydrocarbon fuel cells	Double current density capability of nonaqueous battery systems Fielded low-temperature liquid hydrocarbon fuel cells
Demilitarization of munitions	Materials/Processes Chemical/Biological Defense and Nuclear	Robust reactors for demilitarization to safe products	Mobile seekers for nonstockpile chemical munitions and unexploded ordnance Portable DEMIL reactors	Energetic materials recycling units

Table 4.2–3. Representative Basic Research Goals in Chemistry (continued)

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
Processes (continued)				
Tribology	Materials/Processes Ground and Sea Vehicles Air Platforms	Microscopic model of friction/wear	Sensors to detect friction, wear, corrosion Lubricant design	Combine sensors/ data fusion/lubricant design for prolonged life of rotating machinery
Directed-energy weapons	Weapons	Pulsed, frequency-shifted COIL target illuminator	COIL-based airborne laser High-pressure COIL mixing nozzle/ pressure recovery	Lightweight gas-phase generator to power iodine lasers

4.3 Mathematics

Mathematics research contributes the analytical tools required to satisfy DoD needs in many diverse areas, including advanced materials, manufacturing processes, fluid flow, combustion and detonation, power and directed energy, microelectronics and photonics, sensors, distributed control, optimization, and logistics. Advances in these areas are dependent on research achievements in a number of Mathematics subdisciplines. For example, certain promising approaches to computer vision for automatic target recognition (ATR) require research in a wide range of mathematical topics, including constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, tree-structured methods in statistics, probabilistic algorithms, and distributed parallel computation. Another example is the determination of the dispersion of liquid contents (including chemical and biological agents) of theater-range missiles after interception. Basic

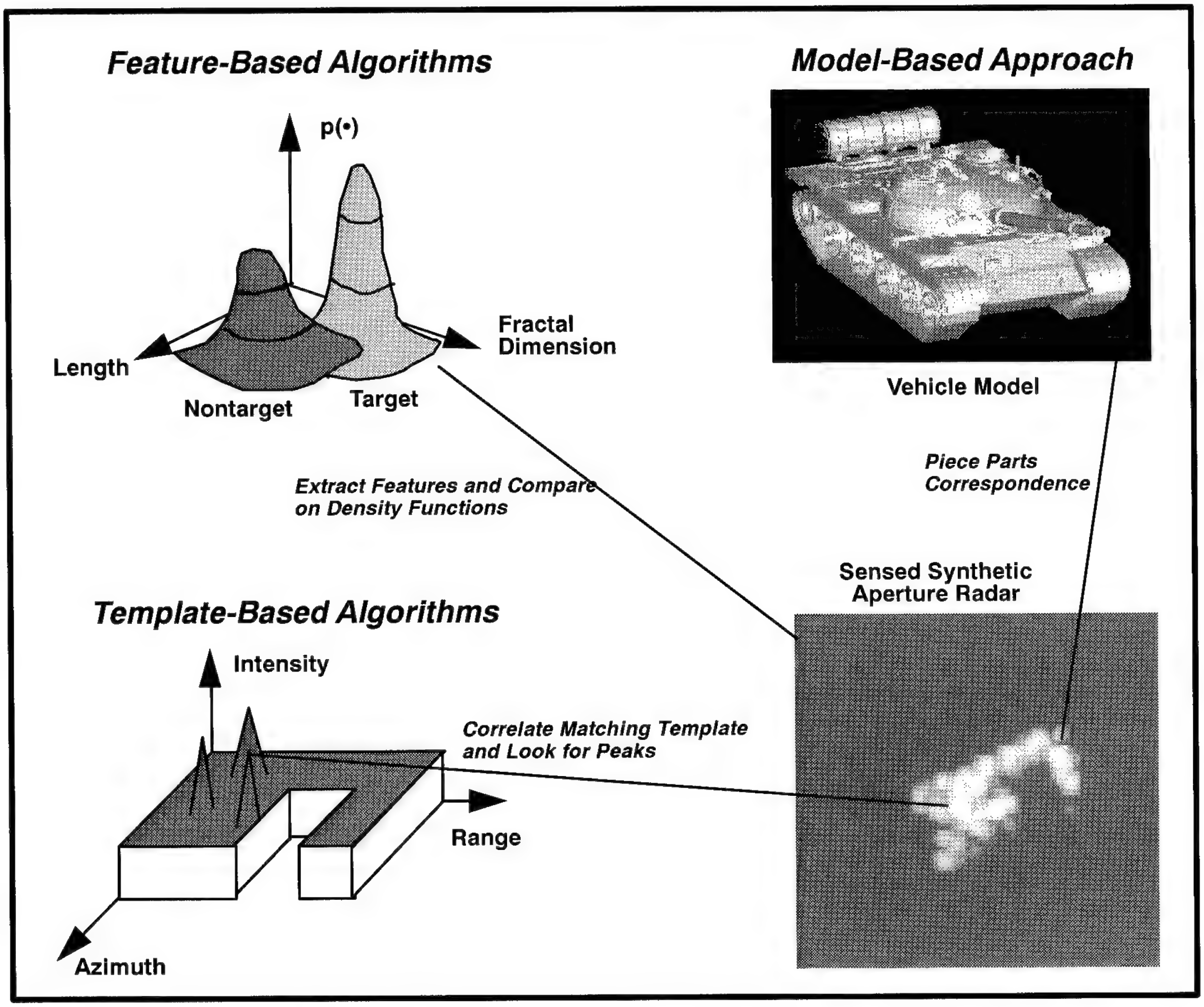


Figure 4–3. Mathematical Algorithms for Automated Target Recognition. New mathematical algorithms are being developed to automatically detect and discriminate military targets of interest. Template-based algorithms coupled with feature extraction methods can be fused to enhance target detectability using sensors such as synthetic aperture radars (SARs). Model-based algorithms can also be used to hypothesize, test, and classify targets.

research in analytical, computational, and experimental fluid dynamics is needed to obtain accurate estimates of the area of liquid dispersion. The Mathematics SPG plans and conducts a balanced program involving both need-driven and opportunity-driven topics.

The services support basic research on nonlinear dynamics and on multiscale phenomena. The results of this research are applicable both to the specific concerns of each service as well as to common issues. Because of the Army's continuing need to improve the performance of advanced armor and antiarmor systems, the Army leads in mathematics research pertinent to the development and performance of advanced materials. The Navy leads in ocean modeling and acoustics. The Air Force leads in control and guidance because of its special needs for weaponry with advanced capabilities in these areas. A major interest in computational mathematics is in adaptive methods. In stochastic analysis and operations research, the prime topic of DoD interest is mathematical programming, reflecting the needs of all three services for improved algorithms for large, complex planning problems and logistics. The Air Force has the lead in compressible and hypersonic flow (for aerodynamic design). The Navy has the lead in random fields (for ocean modeling) and in incompressible flows (for hydrodynamic design). The Army has the lead in probabilistic methods for automatic/aided target recognition. In all three areas of research in Mathematics, there are issues of common interest among the three services as well as issues of particular interest to one or two of the services.

Within the DoD Basic Research Program, research in Mathematics falls into three general subareas:

Modeling and Mathematical Analysis: *The fundamental knowledge provided by research in this area increases DoD's ability to develop advanced ground vehicles, aircraft and naval vessels, energetic materials, delivery systems, radar, sonar, sensors and actuators, and other military equipment.* Research in this area provides the mathematical underpinnings and analytical tools that enhance understanding of complex nonlinear physical phenomena, such as those occurring in advanced materials, fluid flow, acoustic and EM propagation, optoelectronics and neurophysiological systems. Emphasis is on the development of mathematical models—especially nonlinear ordinary and partial differential, difference, and integral equations—and on enhancing the understanding of these models by functional analytical means, often in the context of providing the basis for improving or replacing computational procedures.

Computational Mathematics: *Research in this area impacts DoD capabilities in ballistics, target penetration, vulnerability, ground vehicles, aircraft, naval vessels, combustion, detonation, and stealth technology.* Advanced computational methods are the enabling tools for accurate and reliable simulation of the diverse physical and engineering problems encountered in developing these capabilities. Emphasis is on the development of numerical methods, the development of efficient computational procedures for implementing these numerical methods, and the effective use of the methods in studying dynamic phenomena in complex geometries and media. Accuracy, rigorous error control, and timelines (parallelization) receive particular attention. These results support the effective use of the DoD High-Performance Computing Modernization Program to impact warfighting capabilities.

Stochastic Analysis and Operations Research: *Research in this area impacts DoD capabilities in design, testing, and evaluation of systems; decision making under conditions of uncertainty; logistics; and resource management.* Stochastic analysis and optimization enable improved system design, development, and testing, and also provide the tools for accurate decision making. Emphasis

is on analysis of data by reliable and robust procedures; probabilistic and statistical understanding of physical and operational phenomena with uncertainty; efficient computational procedures for testing and evaluation, especially for cases with very small and very large amounts of data; and efficient optimization techniques.

Budget information for Mathematics research is provided in Table 4.3–1. Table 4.3–2 provides an outline of service-specific interests and commonality in this area. Representative basic research goals for Mathematics in the near and far term are listed in Table 4.3–3.

Table 4.3–1. Basic Research Funding for Mathematics ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601102A	Army	4.8	5.3	5.7
PE 0601104A	Army	2.0	0.3	1.3
PE 0601152N	Navy	2.6	2.6	2.9
PE 0601153N	Navy	17.8	17.3	18.9
PE 0601102F	Air Force	24.1	25.1	29.0
Total		51.3	50.6	57.8

* Program Element names listed in Table 2–2.

Table 4.3–2. Service-Specific Interests and Commonality in Mathematics

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Modeling and Mathematical Analysis
Physical modeling and analysis</td><td>Mathematics of materials science
Reactive flows</td><td>Ocean modeling and mixing
Acoustic propagation and scattering</td><td>Control and guidance
Nonlinear optics</td></tr>
<tr><td colspan="3">Areas of Common Interest: inverse problems (N, AF); multiscale phenomena (A, N, AF); nonlinear dynamics (A, N, AF)</td></tr>
<tr><td rowspan="2">Computational Mathematics
Numerical analysis
Discrete mathematics</td><td>Computational mechanics
Symbolic methods</td><td>Computational acoustics
Computational statistics
Computational logic</td><td>Computational control
Compressible and hypersonic flow</td></tr>
<tr><td colspan="3">Areas of Common Interest: computational geometry (A, N); adaptive methods (A, N, AF); computational electromagnetics (N, AF)</td></tr>
<tr><td rowspan="2">Stochastic Analysis and Operations Research
Statistical methods
Applied probability optimization</td><td>Statistical modeling
Simulation methodology</td><td>Random fields
Spatial line and point processes</td><td>Intelligent search
Chemistry optimization techniques</td></tr>
<tr><td colspan="3">Areas of Common Interest: stochastic image analysis (A, N); stochastic PDEs (A, N); mathematical programming (A, N, AF); network and graph theory (N, AF)</td></tr>
</table>

Table 4.3–3. Representative Basic Research Goals in Mathematics

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
Modeling and Mathematical Analysis				
Armor/antiarmor Sonar Control of missiles Design of projectiles, ground vehicles, aircraft, ships, submarines Precision strike targeting	Information Systems Technology Materials/Processes Weapons	Analysis for penetration of metals Shallow-water sonar High-angle-of-attack missile flight Nonlinear controller for complex systems Multisensor images for targeting	Analysis for penetration of advanced composites Reconfigurable self-designing flight control Vision-directed tracking and control Real-time multisensor images for targeting	Full analysis for penetration of most materials Active control of hypersonic vehicle drag via magnetics Integrated system for real-time multisensor images for targeting
Computational Mathematics				
Armor/antiarmor Sonar Control of missiles Design of projectiles, ground vehicles, aircraft, ships, submarines Precision strike targeting	Information Systems Technology Air Platforms Weapons Ground and Sea Vehicles	Response of portions of vehicles to high loading Medium-size fluid-structure interaction Subcomponent design of complex systems Fast solvers for multisensor images	Response of vehicles to high loading Large-size fluid-structure interaction Subcomponent optimal design of complex systems Real-time solvers for multisensor images	Optimal vehicle design for high loading Detailed fluid-structure interaction under high loading Optimal design of vehicles and weapons Algorithms for multisensor systems
Stochastic Analysis and Operations Research				
Battlefield management Mission planning Real-time logistics Planning for large programs	Information Systems Technology Sensors, Electronics, and Battlespace Environment	Real-time optimization of medium-sized logistics operations Probabilistics methods for deterministically intractable problems Automated cruise missile allocation and routing	Real-time optimization of large logistics operations Improved subpixel target identification using hyperspectral imaging techniques Real-time cruise missile allocation and routing	Optimal design of stochastic network for battlefield management Parallel optimization for materials design (energetic materials, laser hardening) Intelligent onboard decision making for cruise missiles

4.4 Computer Science

Computer Science is central to a variety of DoD issues, including automated acquisition, representation, transformation, fusion, storage, and retrieval of information. The design of intelligent agents, the foundations of heterogeneous and distributed databases, the design and evolution of software systems, and real-time algorithmic and architectural issues for battlefield decision aids are all important DoD areas of interest that involve Computer Science in a critical way. Advanced distributed simulation is an enabling technology for determining and analyzing alternatives for enhancing warfighting capabilities across all services. The realism, interoperability, synchronization, and scaling behavior of modeling and simulation for this purpose need enhancement. Defense research in Computer Science addresses many of these shortfalls by emphasizing work in the areas of software, intelligent systems, and distributed computing and communication. Complete realization of intelligent and flexible manufacturing depends in a critical way on progress made in the subareas of intelligent systems, computer-aided rapid prototyping, and efficient handling of geometric databases. Immersive graphics and visualization techniques will be needed to create virtual environments for design and prototyping.

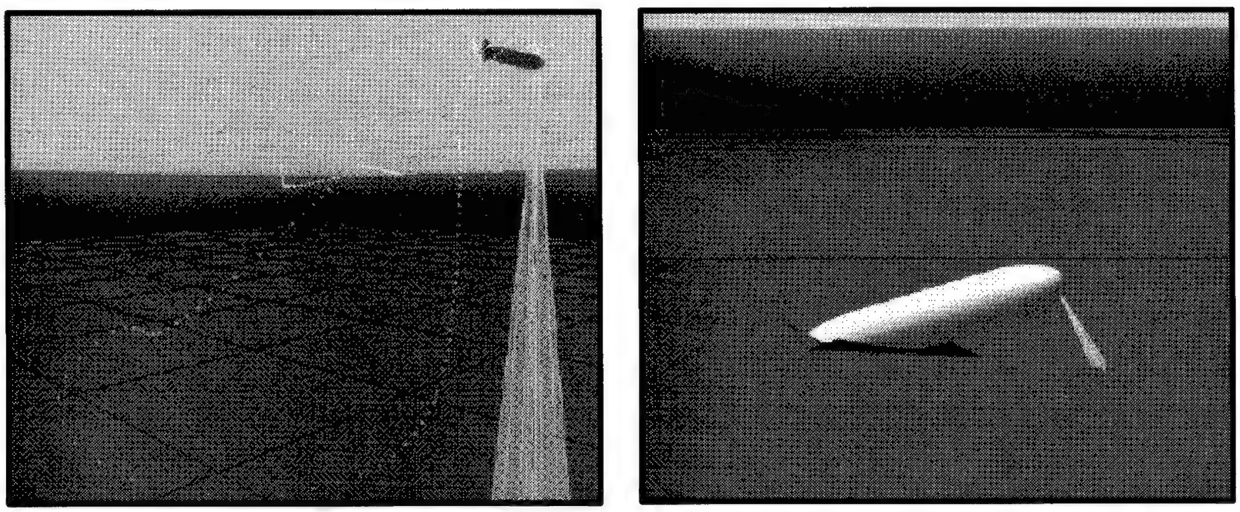


Figure 4–4. Undetected Flaws in UUV Control Software Identified Through Genetic Algorithms. Unmanned underwater vehicles may encounter unpredictable operating environments that cause them to malfunction (e.g., by burrowing into the ocean bottom). Verification techniques based on genetic algorithms are being used effectively to demonstrate the correctness of control software in simulated underwater environments so that UUVs can be deployed with greater confidence.

The diverse needs of the services, driven primarily by requirements associated with different platforms, are the foundation for the topical Computer Science areas pursued within each agency. For instance, while the Navy pursues novel computing concepts with potential to help the fleet accomplish its missions affordably, the Army is driven by requirements pertinent to development of the digital battlefield. Because of demanding computing-speed requirements for aerospace defense, the Air Force has the lead in parallel programming archetypes. In the area of intelligent systems, each of the service research offices has considerable interest and activity. On the other hand, the virtual environments subarea is being pursued primarily by the Army and Navy to support a variety of combat simulation needs and battlespace management applications. Machine vision is

pursued by all services to support reconnaissance and surveillance missions. However, the focus of this research differs significantly for each service due to the widely different regimes in which they operate (land, open ocean and littoral zones, the atmosphere and space).

Within the DoD Basic Research Program, Computer Science research falls into three general subareas:

Intelligent Systems: *The fundamental knowledge provided by research in this area directly affects DoD capabilities in automated C^3I systems, guidance and control of semiautomated and automated platforms, automatic target recognition, and real-time warfare management decision aids.* The principal research thrust in this area involves the design, analysis, and development of systems that can operate autonomously or semiautomatically in dynamic and uncertain environments. Major focal areas include natural language interfaces, the synthesis and design of dynamic networks of agents, high-performance hierarchical and hybrid systems, machine perception and learning, data fusion, and novel computing paradigms for real-time applications.

Software: *Research in this area influences DoD capabilities in automation, decision support, warfare management systems, distributed interactive simulation, digitization of the battlefield, training, and man-machine interaction.* Advanced software is an enabling tool for all of these capabilities. Emphasis is on developing procedures for software prototyping, development, and evolution; on formal methods for software engineering; on knowledge-base/database science; and on efficient and reliable methods for natural language processing in complex situations. The development of sound and efficient computational methodologies for manipulation of large data sets, and the development and analysis of mathematical procedures for information processing and dissemination, networks, communication and information retrieval, are important additional areas of activity.

Architecture and Systems: *This area affects DoD capabilities in warfare management, real-time acquisition, training, C^3I, geographic information systems, automatic target recognition, system automation, distributed interactive simulation, and vulnerability and lethality analysis.* Emphasis is on distributed computing systems for C^3I, dependable multicomputing systems, secure computing, and systems suitable for interaction with humans. Other areas of emphasis include geometric algorithms and modeling, robust geometric computation, dynamic and interactive visualization and navigation through complex 3-D models, and distributed and parallel computing platforms.

Budget information for Computer Science research is provided in Table 4.4–1. An outline of service-specific interests and commonality in this area is given in Table 4.4–2. Representative basic research goals for Computer Science in the near and far term are included in Table 4.4–3.

Table 4.4–1. Basic Research Funding for Computer Science ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601102A**	Army	1.1	10.1	9.9
PE 0601104A	Army	8.3	7.5	10.7
PE 0601152N	Navy	0.8	0.8	0.9
PE 0601153N	Navy	23.2	22.6	24.6
PE 0601102F	Air Force	6.0	6.3	7.3
Total		39.4	47.3	53.4

* Program Element names listed in Table 2–2.

**Supports Army Federated Laboratory initiative for digitized battlefield.

Table 4.4–2. Service-Specific Interests and Commonality in Computer Science

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Intelligent Systems
Control
Learning
NLP
Motion planning
Virtual environments
Data fusion</td><td>Intelligent control
Natural language processing
Machine intelligence</td><td>Case-based reasoning
Machine learning
Motion planning</td><td>Intelligent real-time problem solving
Intelligent tutoring</td></tr>
<tr><td colspan="3">Areas of Common Interest: data fusion (A, AF); machine vision (A, N, AF); virtual environments (A, N); novel computing paradigms (AN, N, AF)</td></tr>
<tr><td rowspan="2">Software
Software engineering
Software environments
Languages</td><td>Heterogeneous database
Formal languages
Automation of software development</td><td>Hard real-time computing
Structural complexity
Programming logic</td><td>Parallel programming archetypes</td></tr>
<tr><td colspan="3">Areas of Common Interest: software environments (A, N, AF); programming languages (A, N, AF); formal design and verification (N, AF)</td></tr>
<tr><td rowspan="2">Architecture and Systems
Compilers
Operating systems</td><td>Scalable parallel combat models
Hybrid systems architectures</td><td>Ultra-dependable multicomputing systems
Secure computing</td><td>Distributed computing for C^3</td></tr>
<tr><td colspan="3">Areas of Common Interest: compiler optimization (A, N); operating systems (A, N, AF); man-machine interface (A, N)</td></tr>
</table>

Table 4.4–3. Representative Basic Research Goals in Computer Science

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
Intelligent Systems				
Intelligent networks Autonomous robots Advanced decision support Common tactical picture	Information Systems Technology Sensors, Electronics, and Battlespace Environment	Medium-scale network of cooperative agents Intelligent agents for structured data Cooperative dynamic systems Medium-scale multimedia networks Learning algorithms for sensor fusion	Large-scale network with mediators Intelligent agents for searching and filtering structured data Intelligent reactive planning algorithms Intelligent interfaces integrated in medium-sized networks	Adaptive network with multifaceted mediators Intelligent agents for common tactical picture Concurrent multi-agent planning Large-scale natural-language-driven information synthesis
Software				
Increased reliability of software Reduced life-cycle costs for large-scale software Affordable, high-performance weapon systems	Information Systems Technology Space Platforms	Formalized semi-automated software engineering Parallel programming archetypes for reusable parallel software Embedded system information structures	Automated engineering of domain-specific software Design techniques for hardware-independent software Automated weapon component design	Automated engineering of general software systems Self-improving software Automated complex weapon system design
Architecture and Systems				
Real-time interactive distributed computing Network security Human-computer interaction Network communications	Information Systems Technology Human Systems	Medium-scale interactive system Formal specification/design for distributed agents for C^3I Multimodal user interface High-data-rate SATCOM for mobile meshes	Adaptable, secure, heterogeneous computer and communication architectures High-data-rate multimedia SATCOM for mobile meshes	Large-scale interactive system Quantum computing Multimodal group interface Multimodal real-time networked interface Two-way high-data-rate mobile SATCOM

4.5 Electronics

Electronics is considered a dominant force multiplier in DoD systems. Basic research in Electronics supports all elements of the JWSTP and is both need and opportunity driven. The Electronics SPG plans and conducts a forward-looking, well-integrated, research program that addresses many of the currently defined mission deficiencies and operational requirements, including aiming and position accuracy of weapons, unmanned robotic vehicles and aircraft, and reliable (minimum downtime) global communications and real-time global surveillance as needed for information dominance. These requirements are driven by *affordability* and *a continuing need for operational superiority.* Operational superiority requires systems possessing higher accuracy and vastly greater information throughput capacity to impact real-time situation assessment or systems performing autonomously over land, at sea, or in the air or space.

The Basic Research Program in Electronics has established a national leadership position and has advanced, exploited, and leveraged research results in many fields that impact technologies

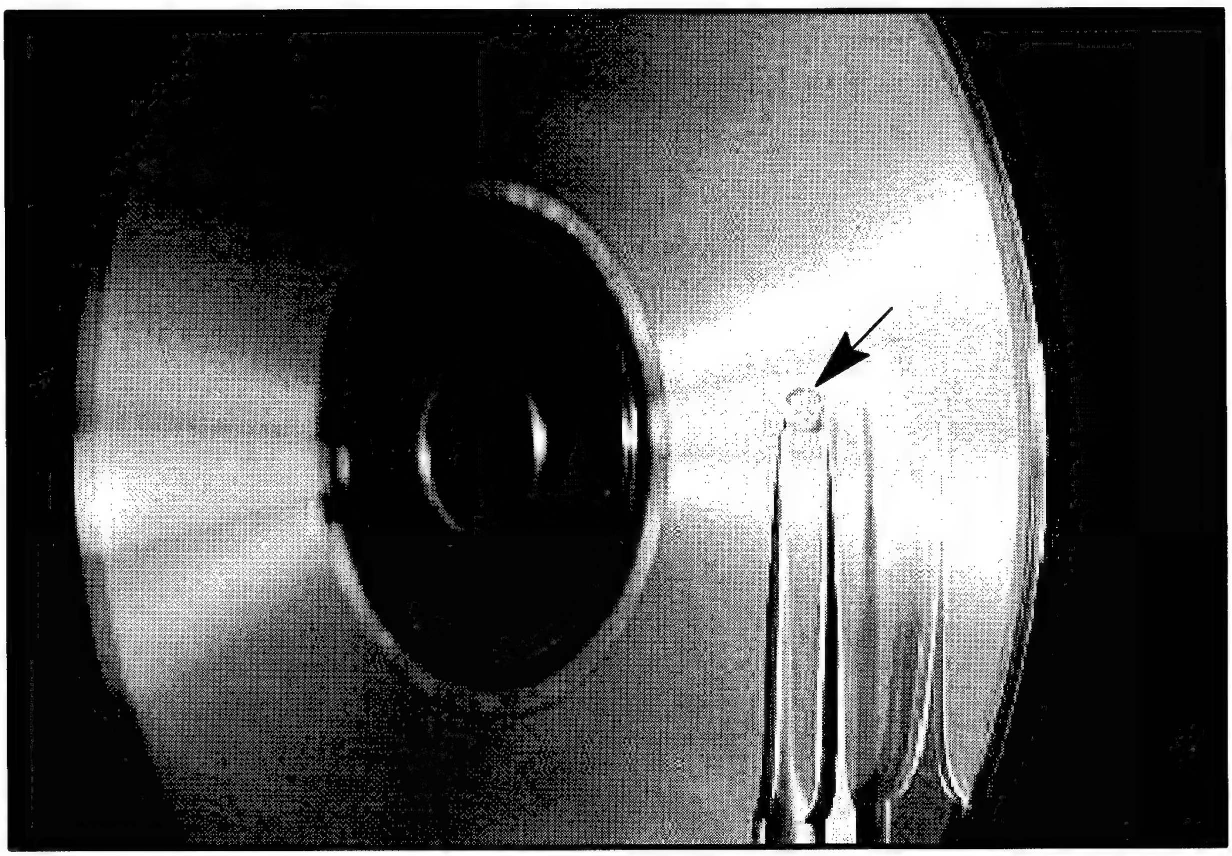


Figure 4–5. New High-Density Digital Memory. An optically accessed, ultra-fast memory device having an areal storage density of 8 gigabytes per square inch has recently been demonstrated by AFOSR-supported researchers at the University of Oregon and the University of Washington. The system employs a YAG (yttrium aluminum garnet) single crystal (arrow) in a stationary configuration that reduces latency associated with rotating disks (100 microseconds file access time) by three orders of magnitude. A standard CD ROM storage disk, shown in the background, has a much lower areal density storage capacity of about 0.5 gigabytes per square inch. This advance will enhance military capabilities in many areas, including the ability of the Air Force to capture, process, store, and transmit images.

of military importance. Representative examples are research efforts on infrared detectors for various military operations under realistic battlefield conditions; wide-bandgap semiconductor research, which is critical for high-temperature jet engine controls and high-power shipboard switching devices; and optical computing devices needed to achieve major weight/size reductions in air and spacecraft signal processors. DoD basic research in Electronics is distributed over the services in a manner that avoids duplication and maximizes benefits to specific service mission requirements. Army research areas are closely coupled to Army mission requirements for ground vehicles and soldier support; Navy programs are driven by considerations derived from ocean and submarine operational needs; the Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. In addition to service-specific programs, the Electronics SPG plans for multiservice and multidisciplinary efforts to more effectively focus resources on recognized high-priority DoD topics.

A widely recognized tri-service effort is the highly successful Joint Services Electronics Program (JSEP) being executed at 13 premier universities in the United States. This program—competitively evaluated, managed, and funded—has led to numerous scientific breakthroughs (laser gyro, communication theory, laser principle, nonlinear optics) and has sponsored the work of five Nobel Prize winners over the last 50 years. The current program pursues multidisciplinary research in the fields of solid-state electronics, quantum electronics, electromagnetics, and information sciences and is completely integrated into the core programs of the services.

The DoD Basic Research Program in Electronics is divided into three subareas:

Solid-State and Optical Electronics: *Research in this subarea will provide the warfighter with novel or improved electronic and optical hardware for acquisition, tracking, electronic controls, radar and communication, displays, data processors, and advanced computers.* Research in solid-state electronics emphasizes topics of limited commercial interest such as low-power, low-voltage applications for soldier or space support; ultra-high-frequency devices to be applied in secure communication or radar; or ultrafast, robust building blocks for future generations of efficient, dedicated supercomputers. Optical electronics, including photonics, takes advantage of the very high bandwidth of transmission channels and aims at massive optical storage as critical building blocks of photonic computation. A new program has been established to understand radiation effects in some semiconductor devices that are based on quantum wells and advanced heterojunctions.

Information Electronics: *Basic research in this subarea will push the performance envelope for wireless communications and decision making by advancing simulation and modeling, coding, and image/target analysis and recognition.* Research in information electronics is dedicated to signal processing for wireless applications and image recognition and analysis. Coding schemes for secure communication and robust communication networks are being investigated. Optimum control of distributed information processing and transmission is also receiving substantial attention. Innovative approaches to modeling and simulation devices and circuits are being pursued. Modeling and sensor fusion, as well as control and adaptive arrays, are also being emphasized.

Electromagnetics: *Progress in electromagnetics will advance DoD capabilities in signal transmission and reception such as found in radar, high-power microwaves, or secure communications in built-up areas.* The electromagnetics research program is focused on fundamentals of antenna design, scattering and transmission of EM signals, and efficient RF components such as vacuum electronics for use predominantly in radar and wireless applications. Computational

electromagnetics is receiving strong emphasis, along with novel approaches to time-domain modeling of electromagnetic wave generation, transmission, and propagation. A substantial part of the program is focused on modeling of millimeter wave phenomena by optical means.

Budget information for Electronics research is provided in Table 4.5–1. A more detailed outline of service-specific interests and commonality in this area is given in Table 4.5–2. Representative basic research goals for Electronics in the near and far term are presented in Table 4.5–3.

Table 4.5–1. Basic Research Funding for Electronics ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	2.7	3.1	3.3
PE 0601102A	Army	14.7	15.3	35.3
PE 0601104A	Army	15.8	14.6	19.0
PE 0601152N	Navy	0.5	0.5	0.6
PE 0601153N	Navy	38.9	37.9	41.3
PE 0601102F	Air Force	25.5	25.7	32.0
Total		98.1	97.1	131.5

* Program Element names listed in Table 2–2.

Table 4.5–2. Service-Specific Interests and Commonality in Electronics

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Solid-State and Optical Electronics
Detectors
Superconductors
Nonlinear circuits</td><td>Uncooled IR detectors
Terahertz electronics
Low-power and voltage analog electronics</td><td>Wide-gap semiconductors
Magnetic thin films
Blue-green semiconductor optics</td><td>Optical computing
Nonlinear optical materials
High-temperature electronics</td></tr>
<tr><td colspan="3">Areas of Common Interest: lithography (A, N); quantum transport (A, N); nanoscale electronics (A, N, AF); heterostructures (A, N, AF); mesoscale devices (A, N, AF); surfaces and interfaces (A, N, AF); device reliability (N, F); superconductors (N, AF)</td></tr>
<tr><td rowspan="2">Information Electronics
Modeling
Simulation</td><td>Coding for wireless communications
Wireless mobile distributed multimedia communications
IR target recognition and image analysis</td><td>Sensor array processing
Distributed networks
Soft/fuzzy logic/neural networks
Reliable, fault-tolerant VLSI</td><td>None</td></tr>
<tr><td colspan="3">Areas of Common Interest: modeling/simulation of circuits, devices, and networks (A, N); sensor fusion (A, N, AF); digital signal processing (A, N, AF); adaptive arrays (A, N, AF); target acquisition (A, AF); array processing (A, N, AF)</td></tr>
</table>

Table 4.5–2. Service-Specific Interests and Commonality in Electronics (continued)

Subarea	Army	Navy	Air Force
Electromagnetics Antennas Transient sensing Tubes	Wireless and radar propagation Quasi-optical devices Printed antennas	Sea ice inverse scattering	Transient electromagnetics Secure propagation
	Areas of Common Interest: integrated transmission lines (A, N, AF); EM numerical techniques (A, N, AF); discontinuities in circuits (A, N, AF); electromagnetic scattering (N, AF); vacuum electronics (N,AF); optical control of array antennas (A, N, AF); power-efficient RF components (A, N, AF)		

Table 4.5–3. Representative Basic Research Goals in Electronics

Area of Military Impact	Relevant DTAP(s)	Year		
		2000	2005	2010
		Solid-State and Optical Electronics		
Prompt decisive combat Sensors and weapon control	Sensors, Electronics, and Battlespace Environment	Improved wide-bandgap semiconductor materials	Wide-bandgap semiconductor devices	Demonstration of multifunctional wide-bandgap semiconductor monolithic circuits
Autonomous systems	Sensors, Electronics, and Battlespace Environment	Stable, reliable, low-voltage devices	Robust, nuclear-hardened, low-power circuits	Ultra-low power, high-density memory
Real-time knowledge of enemy Situational awareness	Sensors, Electronics, and Battlespace Environment Information Systems Technology	Superlattice thermal imagers	Superlattice multispectral imagers	Monolithic multispectral imaging
		Information Electronics		
Information dominance Robust communication	Information Systems Technology	Multiresolution coding	Multiresolution video coding	High-bandwidth, multiresolution video data transmission
Target detection and classification	Information Systems Technology	Hyperspectral data processing	Optical sensor fusion	Sensor fusion of hyperspectral data
Real-time knowledge of enemy Situational awareness	Information Systems Technology Sensors, Electronics, and Battlespace Environment	Distributed multisource, mobile communications	Robust networks	Low-cost, robust, reliable networks for multisource mobile applications

Table 4.5–3. Representative Basic Research Goals in Electronics (continued)

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
		Electromagnetics		
Target detection Precision strike	Sensors, Electronics, and Battlespace Environment Weapons	Efficient cold cathodes	Compact, low-voltage vacuum electronics	High-power, highly efficient, stable fast-wave amplifiers
Target detection Precision strike	Sensors, Electronics, and Battlespace Environment	Optical and electronic phase control of arrays	Predictive models of patch and printed antennas	Conformal multifunction active arrays

4.6 Materials Science

Advanced materials research being conducted as part of the DoD Basic Research Program includes both need-driven and opportunity-driven elements that will impact virtually all DoD mission areas in the future. The Materials Science SPG plans and conducts an aggressive, integrated research program that is leading to new classes of materials possessing increased strength and toughness, lighter weight, greater resistance to combinations of severe chemical and complex loading environments, and improved optical, magnetic, and electrical properties. These advances are focused on meeting the Joint Chiefs of Staff warfighting needs through access to higher performance and superior weapon systems together with improved readiness, decreased need for logistic support, increased reliability, and lower lifetime cost.

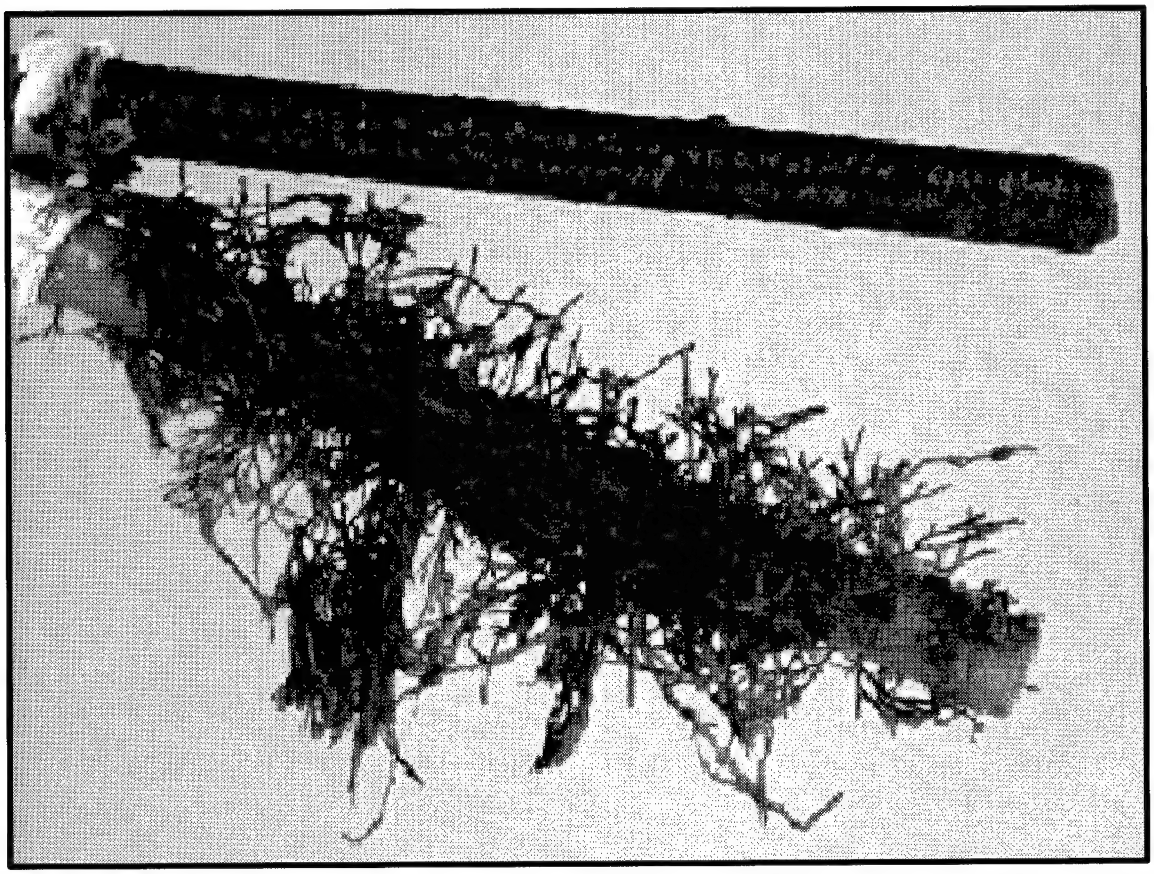


Figure 4–6. Effective Marine Antifouling Achieved Through Lipid Tubules. Lipid tubules—which are bio-derived, self-assembled microstructures—are typically 0.5 μm in diameter, 100–300 angstroms thick, and 30–100 μm long. When tubules containing antifouling agents are placed in marine paints, their long-term controlled-release properties provide an effective defense against marine organisms. The photograph shows two test rods after 6 months' exposure offshore near Hawaii. The rod at the top was coated with a paint that included copper-clad lipid tubules containing Renilla extract, which inhibits fouling; the other rod was coated with only the base paint.

Navy programs are driven by operational considerations such as ocean surface and subsurface vehicle designs as well as naval air, space, and missile system parameters. Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. Army

research areas are closely coupled to Army mission requirements for armor/antiarmor systems, advanced rotorcraft, ground vehicles, missiles, and projectiles. In certain areas of materials research, more than one service has a vested interest in supporting programs. These areas of commonality involve large, diverse, and long-term multidisciplinary efforts. Such efforts are jointly planned through the Materials Science SPG to maximize return on investment. For example, the area of tribology has the potential to impact the operational service life of guns, engines, and aircraft (among many other military systems). The tribology programs were planned with the Army sponsoring work on ion beam engineering/surface modification, the Navy supporting computational and experimental approaches for understanding wear surfaces and interfaces, and the Air Force focusing on failure diagnostics for aging aircraft.

The DoD Basic Research Program in Materials Science includes two subareas: structural materials and functional materials. Research in both subareas includes elements of synthesis, processing, structure, and properties. Theory and modeling also play an important role in these programs.

Structural Materials: *Research in this subarea is needed to satisfy operational requirements of DoD systems such as armor and penetrators; durable, high-temperature components of high-performance engines used in hypersonic air vehicles; and lightweight, tough, corrosion-resistant hulls of naval ships.* Structural materials of principal interest are metallic materials, ceramics, composites, and polymers. The structural aspects pertain primarily to service under mechanical loads. Research thrusts in this area are focused on microstructural design and processing of new materials to achieve higher performance and improved reliability at lower costs, development of unique nanostructures and microstructures, improved understanding of materials under complex loading and environmental conditions, mechanics and chemistry of interfaces, and innovative nondestructive techniques for characterizing interrelationships between processing and performance of advanced materials. Some of the research areas of growing importance pertinent to these thrusts include computational design, aging systems, biomimetics, and nanomaterials. The area of aging systems is of particular concern for all three services in that research results may provide new opportunities for affordably maintaining and upgrading aging assets. Each of the services is investing in multidisciplinary research focused on meeting this long-term need. Research is focused in the areas of corrosion and degradation, failure mechanisms, and life prediction and life management, with each service concentrating on the special materials and structural aspects of its unique platforms and collaborating in more generic areas.

Functional Materials: *DoD systems that are affected by research in functional materials include a host of electronic devices and components; mobile and fixed electro-optical communication equipment; radars, sonars, and other detection devices; displays; readers; and power-control devices.* Research in this area is focused on understanding and controlling materials processes to achieve affordable and reliable performance, materials-by-design to provide new materials with unique properties, principles of defect engineering, and nanotechnology. Areas of growing importance include nanostructures, smart systems, and thermoelectrics. For example, in the area of thermoelectrics, novel material approaches that include lead-telluride (PbTe)-based superlattices, skutterudites, and organic composites are being pursued. These materials offer new opportunities for low-temperature cooling of night-vision equipment and electronics, and for high-temperature applications for shipboard cooling and power generation.

Budget information for Materials Science research is provided in Table 4.6–1. An outline of service-specific interests and commonality in this area is included in Table 4.6–2. Representative basic research goals for Materials Science in the near and far term are cited in Table 4.6–3.

Table 4.6–1. Basic Research Funding for Materials Science ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	2.6	2.7	2.9
PE 0601102A	Army	7.0	7.6	8.4
PE 0601104A	Army	2.5	2.9	3.0
PE 0601152N	Navy	1.8	1.8	2.0
PE 0601153N	Navy	32.6	31.7	34.6
PE 0601102F	Air Force	13.1	13.8	17.0
Total		59.6	60.5	67.9

* Program Element names listed in Table 2–2.

Table 4.6–2. Service-Specific Interests and Commonality in Materials Science

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Structural Materials
Synthesis
Processing
Theory
Properties
Characterization
Modeling</td><td>Manufacturing science (land/rotorcraft systems, armaments)
Armor/antiarmor materials
Diesel engine materials
Gun tube liner materials</td><td>Marine corrosion, oxidation, and fatigue
Advanced materials for ships and submarines
Acoustically damped structures
Layered designed materials</td><td>High-temperature fatigue and fracture
Aerospace skin materials
Aging aircraft
Functionally graded materials
Hypersonic skin
Balanced material properties</td></tr>
<tr><td colspan="3">Areas of Common Interest: advanced composites (A, N, AF); adhesion/joining (A, N); tribology (A, N, AF); ceramics (A, N, AF); intermetallics (N, AF)</td></tr>
<tr><td rowspan="2">Functional Materials
Synthesis
Processing
Theory
Properties
Characterization
Modeling</td><td>Defect engineering
Gradient index optics
IR detectors
CBD materials
Smart materials</td><td>Ferrite films
Ferroelectrics
Diamond
Acoustics/active materials
Electronic packaging materials
Superconductivity</td><td rowspan="2">(Topics addressed under Chemistry, Electronics, Physics, and Mechanics basic research areas)</td></tr>
<tr><td colspan="2">Areas of Common Interest: optoelectronics (A, N); magnetic materials (A, N)</td></tr>
</table>

Table 4.6-3. Representative Basic Research Goals in Materials Science

Area of Military Impact	Relevant DTAP(s)	Year: 2000	Year: 2005	Year: 2010
Structural Materials				
Aging systems	Materials/Processes	Noninvasive techniques for corrosion detection	Methodology for aging aircraft structural integrity	Real-time, condition-based maintenance
Aircraft structures	Air Platforms	Simple smart structures for increased performance	Active control structures for structural integrity and stealth	Robust, active controlled, multifunctional structures
Advanced armor	Ground and Sea Vehicles	Resin transfer molding of integral armor	Hybrid nanocomposite armor materials	Multifunctional, lightweight armor materials
Ship/sub hulls and machinery	Ground and Sea Vehicles	HSLA weldable steels (>100 ksi) without preheat	Low-carbon weld metals/hull steels at increased strength	Laser weld process for automated fabrication of ship hulls
Functional Materials				
Active/passive and imaging sonar	Materials/Processes	Single-crystal piezoelectrics of 90% electromechanical coupling	Electromechanical transducer materials with strains of 1–3%	First-principle calculations of new piezoelectric materials
Communications	Materials/Processes	Magnetic biasing films for MIMIC	Integrated ferrite/silicon structures with bulk properties	Frequency-agile receivers
Target acquisition	Materials/Processes	Adaptive opto-mechanical systems	Thermoelectric-based cooling systems	Broadband sensor protection
Data storage and sensors	Materials/Processes	Thin-film, nonvolatile, high-density magnetic memory metals	Magnetic-film sensors with 10x improved sensitivity	Magnetic-film storage materials for >10 Gbytes/in^2

4.7 Mechanics

DoD-sponsored basic research in Mechanics represents the major national effort in this field. The overall scientific goal is to understand and control the response of complex phenomena for various military applications, including combat vehicles and weapon systems. Such understanding results in new capabilities for designing weapons, platforms, and subsystems that meet desired performance levels, offer enhanced survivability, and have predictable costs. There is an increasing DoD need for these advanced capabilities because (1) modern demands for simulation-based design data to support acquisition decisions place a premium on the ability to accurately forecast system capabilities, and (2) longer service lives of major system acquisitions increase demands for major performance improvements with predictable affordability constraints.

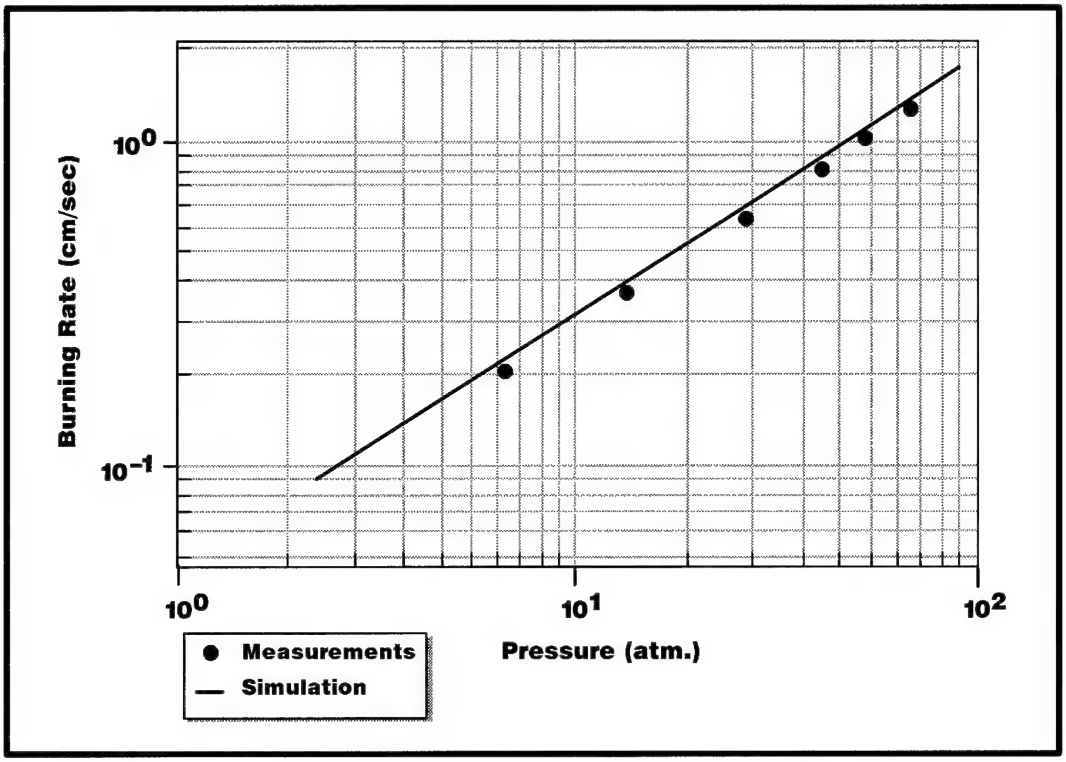


Figure 4-7. Comparison of Predicted and Measured Burning Rates for a Solid Propellant (RDX). Predicting the burning rate of solid propellants requires inclusion of the proper set of chemical reactions in thermofluidynamical calculations. Such a large set (over 130 reactions) was used to predict the burning rate of a monopropellant (RDX) using parallel supercomputers. This accomplishment will lead the way for understanding propellant combustion at realistic high pressures and estimating the combustion properties of new propellants without extensive and expensive testing. (These predictions were derived from a one-dimensional analysis; work to achieve three-dimensional analytical capabilities is in progress.)

Mechanics, as an engineering science, is closely tied to the issue of complexity. Complexity manifests itself in several ways, such as the extremely large range of scales present in a phenomenon, or the plethora of simultaneous interactions that govern its dynamics. Research in Mechanics is focusing on understanding relationships between microscale phenomena and macroscale response; submicroscale mechanical response devices for obtaining service-history data; inventing new concepts for predicting and controlling strongly nonlinear/dynamic phenomena; conducting

interdisciplinary work with synergistic ideas from analysis, simulation, and diagnostics; and determining the appropriate level of complexity relevant to engineering. These characteristics, alone or in combination, are present in all DoD research in Mechanics. Major research tools include modeling based on new concepts in analysis and optimization; simulation, often taxing the largest of modern parallel supercomputers; and diagnostics, which measure spatial-temporal variations of multiscale phenomena.

Mechanics research supported by the DoD Basic Research Program can be conveniently divided into three general subareas: solid and structural mechanics, fluid dynamics, and propulsion and energy conversion. Each service performs research responsive to its particular system drivers. In a number of areas, the services have common interests. In general, each service performs research in an area of commonality, with specific nonoverlapping technology targets. For example, in structural dynamics and smart structures, the Army emphasizes stability and control of rotorcraft structures, the Navy focuses on underwater explosion effects and structural acoustics, and the Air Force targets fixed-wing aeroelasticity and engine dynamics.

Solid and Structural Mechanics: *Research in this area deals with the identification, understanding, prediction, and control of multiscale phenomena that affect the properties and reliability of modern DoD structures.* Such phenomena range from fracture and fatigue initiated at micromechanical levels to multiple-scale interactions that need to be quantified in order to optimize the dynamics of complex structures. Fracture alone costs DoD billions of dollars every year. Emphasis is in integrating knowledge from micro to macro level and on macro-optimization. Research on "smart" structures integrates actuators, sensors, and control systems into the structure to accomplish damage control, vibration reduction, and reconfigurable shapes (e.g., smart helicopter rotor blades). Opportunities exist for optimizing lift-to-drag ratio, increasing lift, expanding the flight envelope, and reducing required installed power on DoD air vehicles. Solid mechanics research addresses finite deformation and failure mechanisms, penetration mechanics, and computational mechanics. Reliability of ship structures, underwater explosion effects, structural acoustics and dynamics, shock isolation/vibration reduction in machinery, and noise control are addressed. A growing area of interest is the micromechanics of semiconductors, interconnects, and packaging for power electronic building blocks (PEBBs) used for power distribution. High-cycle-fatigue issues are addressed by new multidisciplinary research in structures, materials, aerodynamics, and control of turbomachinery. The anticipated products are physics-based models for response prediction, an enhanced understanding of unsteady and transient engine behavior, and robust active control.

Fluid Dynamics: *The design, performance, and stealth of DoD weapons, platforms, and subsystems depends on tailoring the distributed fluid mechanical loads that control their dynamics.* Modern supercomputers, whole-field laser diagnostics, sophisticated turbulence models, and microelectromechanical actuators are used, alone or in combination, to produce validated prediction/control methods. Central to fluid dynamics research is the understanding, prediction, and control of turbulent flows with high Reynolds numbers. Such flows can be rotorcraft wakes, unsteady flows around maneuvering fighters, or multiphase flows around marine propulsors. Increased attention is being given to the coupling of helicopter rotor aeroacoustic fields and structural deformation, the understanding of compressibility, and full-scale Reynolds-number effects in aerodynamics and hydrodynamics. Simulations of high-speed flows in complex configurations relevant to hypersonic vehicles are being pursued, with emphasis on integrated approaches to inlets, supersonic combustion, and nozzles. Interdisciplinary research explores intelligent flow control strategies using micro-

electromechanical systems (MEMS) for thrust vectoring, high lift, drag reduction, and noise/signature reduction. An important new focus involves simulations of free-surface/two-phase flows around surface ships, understanding and predicting the behavior of maneuvering undersea vehicles, and exploring supercavitation phenomena for high-speed undersea weapons.

Propulsion and Energy Conversion: *Research in this area is crucial to the performance/stealth of DoD weapons or platforms. The research is inherently and strongly multidisciplinary, combining knowledge from chemical kinetics, multiphase turbulent reacting flows, thermodynamics, detonations, plasmas, and control.* Increasing emphasis and growth expectation are being given to active sensing, actuation, and control for engines, and integration into an intelligent engine model; high-pressure kinetics; and combustion diagnostics. Another research focus involves synthesizing new energetic materials/fuels, characterizing their behavior, and controlling their energy release rates for specific DoD weapon applications. Research on the physical, chemical, and material interactions in solid propellants, at realistic pressure environments, addresses their combustion mechanisms. Active combustion control is being pursued for tailoring tactical missile motor behavior and compact shipboard incinerators. High-performance aircraft require engines with high operating temperature and pressure. Research to achieve more efficient and durable combustion dynamics and high-thermal-capability (supercritical) fuels is being conducted.

Budget information for Mechanics research is provided in Table 4.7–1. service-specific interests and commonality in this area are cited in Table 4.7–2. Representative basic research goals in Mechanics over the next 15 years are provided in Table 4.7–3.

Table 4.7–1. Basic Research Funding for Mechanics ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	2.2	2.3	2.3
PE 0601102A	Army	14.4	17.4	16.1
PE 0601104A	Army	13.7	17.0	15.5
PE 0601152N	Navy	3.2	3.2	3.5
PE 0601153N	Navy	30.9	30.0	32.8
PE 0601102F	Air Force	33.0	32.4	42.0
Total		97.4	102.3	112.2

* Program Element names listed in Table 2–2.

Table 4.7–2. Service-Specific Interests and Commonality in Mechanics

Subarea	Army	Navy	Air Force
Solid and Structural Mechanics Structural dynamics Composites Aeroelasticity Acoustics	Finite deformation, impact, and penetration	Structural acoustics Thick composites Micromechanics of electronic devices and solids	Hypersonic aeroelasticity Mechanics of high-temperature materials Particulate mechanics
	Areas of Common Interest: structural dynamics and control (A, N, AF); damage and failure mechanics/quantitative nondestructive evaluation (A, N, AF); smart structures (A, N, AF)		
Fluid Dynamics Aerodynamics Turbulence Unsteady flow	Rotorcraft aerodynamics Rotorcraft aeropropulsion Projectile aeroballistics	Free-surface phenomena Hydrodynamic wakes Hydroelasticity and hydro-acoustics	Turbomachinery aerothermo-dynamics Fixed-wing aerodynamics Hypersonic aerothermo-dynamics
	Areas of Common Interest: unsteady separated flow (A, N, AF); turbulence (N, AF)		
Propulsion and Energy Conversion Gas turbines Explosives Soot formation	Reciprocating engines Gun propulsion Small gas turbines	Underwater propulsion Missile propulsion Explosives	Large gas turbines Supersonic combustion Spacecraft and orbit propulsion
	Areas of Common Interest: high-energy materials combustion/hazards (A, N); soot formation (A, N, AF); turbulent flows (A, N, AF); spray combustion (A, AF)		

Table 4.7–3. Representative Basic Research Goals in Mechanics

Area of Military Impact	Relevant DTAP(s)	Year		
		2000	2005	2010
Solid and Structural Mechanics				
Ship survivability	Ground and Sea Vehicles	Dynamic fracture criteria for welding	Coupled local-global simulation	Validated simulation of underwater explosion effects
High-performance helicopters	Air Platforms	Smart rotor blade concept	Integrated aero-mechanics analysis for maneuvering rotorcraft	Embedded smart vibration control concepts
Gas turbine engine performance	Air Platforms	Engine model for response prediction	Understanding transients	Robust active control transition
Fluid Dynamics				
Ship signature effects	Ground and Sea Vehicles	Reynolds Average Navier Stokes (RANS) for surface ships	Two-phase flow simulation	Two-phase flow ship simulations
High-performance helicopters	Air Platforms	Coupled structural deformation/aero-acoustic models	Full Reynolds/Mach number simulation of dynamic stall	Aerodynamic simula-tion of maneuvering helicopter
Hypersonic aircraft	Air Platforms	Inlet flow simulations	Understanding of nozzle physics	Simulations of integrated inlet/combustor/nozzle

Table 4.7–3. Representative Basic Research Goals in Mechanics (continued)

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
Propulsion and Energy Conversion				
Gun propulsion techniques	Weapons	Liquid-propellant hazard kinetics	Accurate ram accelerator models	Multiphase interior ballistic models
New missile propellants	Weapons	Chemistry/material/ flow model	Prediction/control of rocket motors	Difluoramino-based propellants
High-performance liquid-fuel engines	Weapons	Physics of supercritical fuels	Low-emission supercritical fuels	Supercritical fuels in engines

4.8 Terrestrial Sciences

Research in Terrestrial Sciences is almost entirely supported by the Army. Navy interests are limited to ice mechanics, a collaborative effort with the Army. The vast majority of related Navy work is reported under Ocean Sciences (Section 4.9). The Air Force program in solid-earth physics—limited to seismology in support of global monitoring of a nuclear test ban—has recently been terminated by Department of Defense Program Budget Decision 203C, dated 22 January 1996. The subject of environmental quality, which is included as a subarea of Terrestrial Sciences research by the Army, is assigned to different technical areas by the other services.

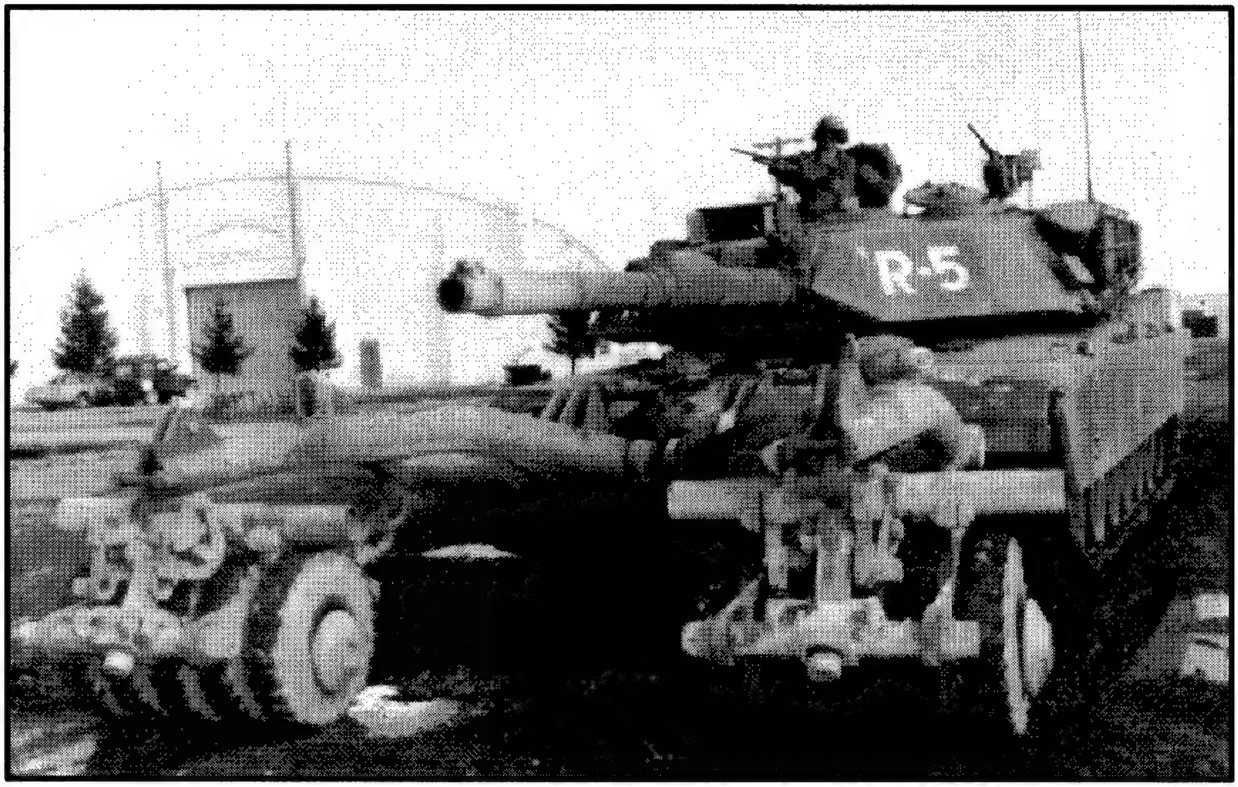


Figure 4–8. Rough Terrain Traversal by Heavy Armor. Army M1A1 Abrams main battle tanks outfitted with mine rollers are being used in Bosnia and Herzegovina during Operation JOINT ENDEAVOR. Basic research work in Terrestrial Sciences involving the characterization of traction-related ground properties improves our ability to predict the tactical mobility of both wheeled and tracked vehicles over natural terrain, thereby contributing to the planning and execution of various ground combat operations.

The requirement for research in the Terrestrial Sciences stems from the impact that the physical environment has on virtually all aspects of Army activity. Programs of theoretical and experimental research in the solid-earth and hydrologic sciences are required to support DoD missions in a wide variety of circumstances. To be successful, the modern CONUS-based power-projection Army must be able to perform at full capability throughout the world, in operational theaters that may range from equatorial to polar latitudes, and in terrain that may vary from coastal beaches and lowlands to deserts and mountains. The objective of the 21st Century Digital Battlefield requires detailed information regarding distributed terrain conditions and a sophisticated capability for terrain information processing, analysis, and visualization. Despite continuing Army efforts to

develop an all-weather/all-terrain capability, terrain and environmental conditions still constrain Army operations, particularly in areas of climatic extreme and in adverse environments. Thus, in the Terrestrial Sciences context, there is a particular Army need for an improved ability to better understand terrain and utilize terrain information for military purposes. An Army commitment to environmental stewardship is supported through research related to environmental quality.

The DoD Basic Research Program in Terrestrial Sciences comprises four subareas:

Solid-Earth Sciences: *Research in solid-earth sciences encompasses both field studies and laboratory research related to the acquisition, analysis, interpretation, and modeling of information about terrain and terrain behavior under different climatic conditions.* Research on terrain characteristics and behavior is aimed at enhancing the current capability to interpret and utilize remotely sensed information about topography, natural features and manmade objects, and short-term battlefield surface conditions and dynamics at a variety of scales. Other aspects of terrain research focus on multispectral approaches to terrain remote sensing, physical and theoretical terrain characterization, and the automated generation of terrain databases and analysis of terrain information. Areas showing increased attention are interferometric synthetic aperture radar (IFSAR), elevation matrix generation, high-resolution airborne sensor exploitation, and hyperspectral automated image classification. Integrated terrain analysis, modeling, visualization, and simulation are also important areas being pursed in these research efforts.

Snow, ice, and frozen ground occur either occasionally or continuously from the mid-latitudes poleward; depending on particular conditions and equipment availability, they can either enhance or hinder survivability and operational mobility. Research in snow, ice, and frozen ground derives from specific needs to better understand the physical and mechanical behavior of these materials. Current efforts are focused on energy propagation processes, biogeochemical processes, and the physical and mechanical properties and behavior of snow, ice, and frozen ground. Areas of emphasis for the near future are ice physics and the mechanical behavior of ice at intermediate to large scales. Ice adhesion is also a subject of increasing interest and activity. The Navy supports work involving sea ice and arctic marine environments.

Surficial Processes: *Research in surficial processes is directed toward enhancing Army operational mobility through improved characterization of the dynamics of surface and near-surface terrestrial environments, and through better understanding of the dynamic processes that form and modify surficial landscapes.* Of particular interest are the highly interrelated hydrometeorlogical, hydrologic, and hydraulic processes of the hydrologic cycle. Because the Army is responsible for logistics over-the-shore (LOTS), research to more fully understand the hydrodynamic and sedimentary processes that form and modify beaches is an important Terrestrial Sciences requirement.

Current research addresses the mobility issue from several different perspectives. One major effort is directed toward modeling the dynamic interactions of wheeled and tracked vehicles with soil in the context of offroad mobility. Another important effort seeks to understand the fundamental structure of drainage basins, the mechanisms of runoff generation, and the effects of temporal/spatial variability of precipitation on runoff hydrography; the aim of this work is to achieve real-time prediction and modeling of the hydrologic response of basins to precipitation events of different magnitudes and durations. Other efforts are focused on subsurface hydrologic modeling, sediment mechanics and erosion processes, and geostatistical analysis. Areas of increasing emphasis include the evaluation of soil response to transient loading, coastal processes and dynamics, atmosphere-

terrain dynamic interaction, space-time variability in hydrologic systems, and the dynamics of basin/landscape evolution. Geophysical remote sensing efforts have recently commenced that are directed toward the seismic detection of shallow sedimentary features, voids, and buried objects.

Environmental Quality: *The Army is committed to a policy of environmental stewardship based on the four pillars of compliance, restoration, pollution prevention, and conservation.* Therefore, research is being undertaken to provide the Army with required capabilities for conducting activities in compliance with all federal, state, local, and host-nation regulations; cleaning up contaminated sites at Army installations; eliminating pollution at its source; and appropriately managing natural and cultural resources on Army installations.

Structures and Facilities: *Research in structures and facilities is responsive to important Army issues concerning the survivability of airfields, pavements, and structure.* Current efforts relate to improved pavement performance, modeling the response of pavements to static and dynamic loading, the development of materials for multispectral camouflage, development of high-performance cement-based materials, constitutive modeling of geological and structural materials, projectile penetration into geological and structural materials, and structural analysis of deformable projectiles during penetration. Topics of increasing importance for the future are pavement overlays and interfaces, modeling of thixotropy, testing and simulation of advanced penetrators into concrete structures, structures in rock, and high-strength, high-ductility structural materials, and the interaction of high-velocity projectiles with geological and structural targets during penetration.

Budget information for Terrestrial Sciences research is provided in Table 4.8–1. Service-specific interests in this area are described in Table 4.8–2. Representative basic research goals in Terrestrial Science for the near- and far-term are presented in Table 4.8–3.

Table 4.8–1. Basic Research Funding for Terrestrial Sciences ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	0.7	0.8	0.8
PE 0601102A	Army	18.0	18.7	17.2
PE 0601102F	Air Force	5.0	0.0	0.0
Total		23.7	19.5	18.0

* Program Element names listed in Table 2–2.

Table 4.8–2. Service-Specific Interests in Terrestrial Sciences

Subarea	Army	Navy	Air Force
Solid-Earth Sciences Sources Detection	Remote sensing Environmental quality Digital topography Terrain, vegetation scatter Snow, ice, frozen ground Soil mechanics	Marine ice mechanics (funded under Ocean Sciences)	None
Hydro-dynamics and Sedimentary Processes	Tactical mobility LOTS Geomorphology Hydrology	None	None

Table 4.8–3. Representative Basic Research Goals in Terrestrial Sciences

Area of Military Impact	Relevant DTAP(s)	Year		
		2000	2005	2010
		Solid-Earth Sciences		
Force projection	Materials/Processes	Dynamic soil deformation algorithms for mobility models	Algorithms describing repetitive vehicle loading on deformable soils	Constitutive algorithms for predicting temporal response of soils
Surveillance and target recognition	Sensors, Electronics, and Battlespace Environment	Neural network terrain data classification	Direct 3-D imaging of terrain	Fully automated real-time terrain visualization
Force projection	Materials/Processes	Multiphase continuum models for penetration and ground shock	High-resolution internal diagnostics for soil characterization	Plasma hardening of soils
Force projection	Materials/Processes Sensors, Electronics, and Battlespace Environment	Snow friction effect for wet and dry snow	Model effects of snow chemistry on millimeter-wave response	Determination of impact of winter environmental conditions on emerging sensing devices
Force projection	Materials/Processes Sensors, Electronics, and Battlespace Environment	1–10 km resolution sea ice model	Coupled ocean-ice model	Coupled air-ocean-ice model
		Hydrodynamics and Sedimentary Processes		
Force projection	Materials/Processes Sensors, Electronics, and Battlespace Environment	Scaling effects in hydrologic systems	Constitutive model for soil-vehicle interaction	High-resolution simulator of space-time rainfall for mobility assessment
Force projection	Materials/Processes	Constitutive relations for sediment transport	Beach-bar evolution model	Predictive model for characterizing beach erosion on short timescales

4.9 Ocean Sciences

Because the oceans are the Navy's principal operating environment, robust competency in Ocean Sciences is a core requirement and responsibility of the U.S. Navy. The Army has mission interests in joint logistics-over-the-shore (JLOTS) coastal engineering. These two services share a common interest in near-shore/beach processes and in coastal waves.

Important phenomena and parameters in the Ocean Sciences include tides, currents, temperature and salinity of the water column, surface and internal waves, ocean fine structure, surf, optical properties, bubbles, and biological and chemical contents. The dominant area of scientific and technological advance is in nowcasting and forecasting the ocean and its acoustic, optical, and electromagnetic features from the bottom to the surface. The domain for this advance extends from the open ocean to the beach.

DoD-supported Ocean Sciences research includes work in three subareas:

Oceanography: *The fundamental knowledge provided by research in oceanography impacts Navy capabilities to operate in the ocean, and the ability to use its sensors and weapons effectively.* Both Army and Navy capabilities in the coastal and beach regimes are addressed. Kilometer or higher resolution thermal structures, nowcasts, or forecasts may be adequate to resolve the ocean scales to support low-frequency active acoustic systems in the open ocean. However, the littoral zones of the world (e.g., marginal shelves, shallow water coastal regions) require much finer resolution to nowcast/forecast the four-dimensional ocean environment in support of operations such as amphibious assault, special operations, and mine countermeasures (MCM). Research thrusts include regional prediction of ocean surface wave conditions and their time evolution, which affect JLOTS; ship-based models for western boundary currents (e.g., the Gulf Stream) to permit environmentally adaptive prosecution of antisubmarine warfare and safer carrier operations; studies of the rate of conversion of dimethyl-sulfide to sulfur dioxide for projecting aerosol concentrations, which influence the performance of lower atmosphere electro-optical systems in the marine environment; and investigation of a laser-line-scan (LLS) fluorescence mapper for benthic spectra to aid optical detection of mines in shallow water. Recent accomplishments include the discovery of ultra-thin layers of oceanic biological activity materially affecting undersea optical surveillance; completion of a major field experiment (Duck–94) to measure the full spectrum of near-shore processes simultaneously; elimination of wind forcing as an important process for cross-shelf transport, thus simplifying the data requirements for near-shore DoD operations; and development of a full Boltzmann shallow-water wave model, which impacts the accuracy of coastal wave predictions in support of JLOTS and expeditionary warfare.

Ocean Acoustics: *Oceanography affects the Navy's capabilities to detect, classify, and neutralize undersea enemy systems and activities.* The ocean is transparent to sound propagation, so fundamental knowledge of ocean acoustics is key to system design, operating strategies, and tactical decisions. Recent accomplishments include identification of the importance of range dependence for shallow-water acoustics, providing enhanced detection and classification of diesel submarines in coastal environments; development of an efficient poro-elastic numerical code for high-frequency acoustics, critical to effective mine hunting and torpedo guidance in shallow water; identification of internal waves as significant scatterers for long-range acoustic propagation, affecting acoustic systems design to regain acoustic superiority in deep water; and demonstration that

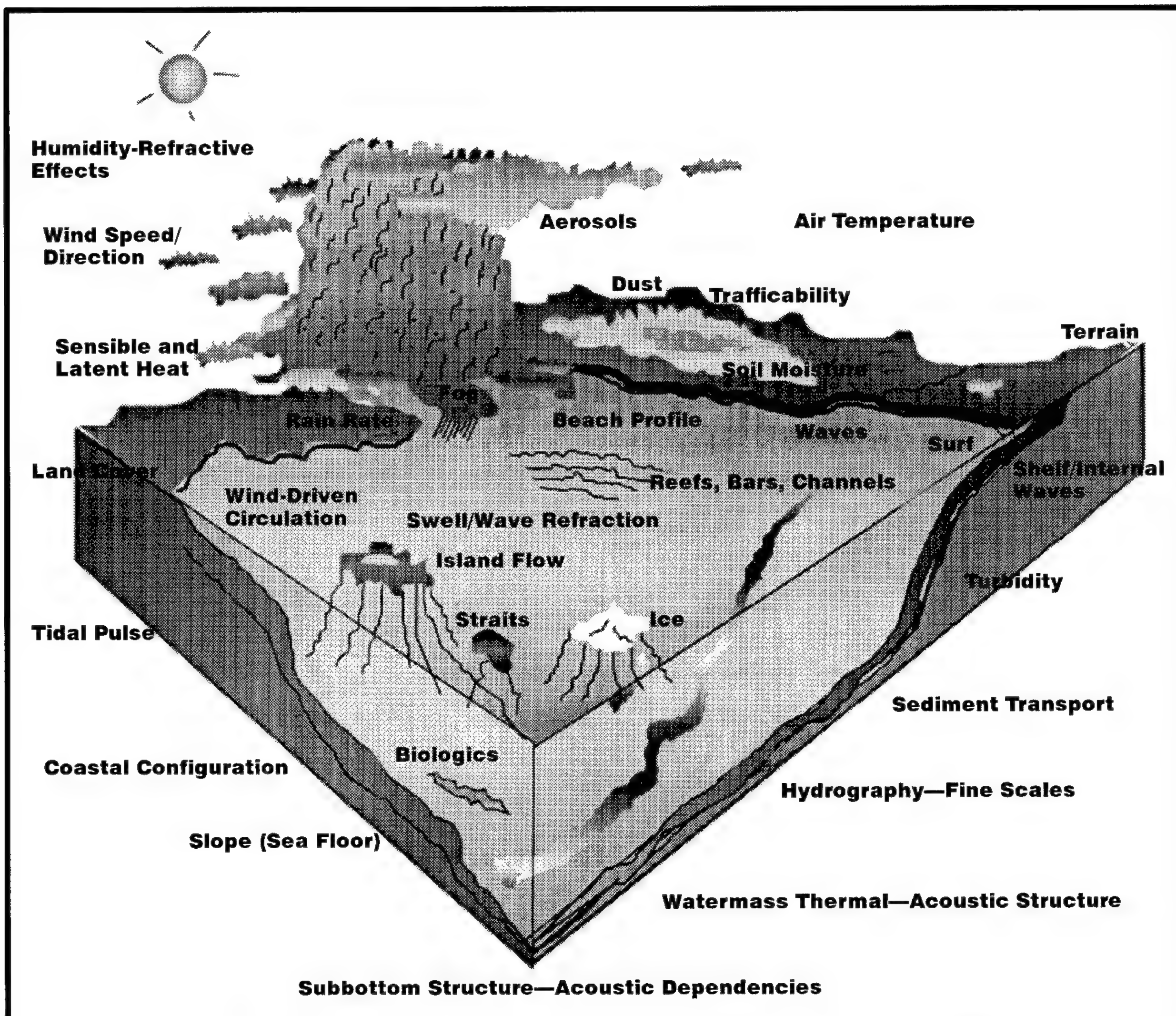


Figure 4–9. The Littoral Environment. The littoral operating environment is one of great complexity and rapid changes, including complicated boundaries at the coast and bottom of the ocean; rough and variable coastal topography; large, dangerous, and quickly varying surface waves; freshwater runoff to the ocean from rivers and estuaries; saltwater intrusion (and wave action) on the land; meteorological conditions that change rapidly in time and space; major offshore ocean forcing that is difficult to measure or forecast; and ubiquitous anthropogenic influences (commerce, noise, pollution). Characterization and prediction of the littoral battlespace is difficult on land, in the ocean, and in the atmosphere, yet half the world's population lives within 50 miles of the coastline; today's warfighter must thus be able to operate in the littoral realm and to exploit environmental variability. The approach in basic research is to blend observations from remote sensing and on-scene sensors with historical databases, using physics-constrained models as smart and adaptive interpolators, extrapolators, and predictors. These models are validated and demonstrated in applied research and developmental efforts.

multiple upper ocean parameters will be needed to estimate ambient noise, thus giving a tactical edge in acoustic prosecutions in the littoral region.

Ocean Geophysics: *This area affects both Navy and Army capabilities to work in the ocean and at its boundaries, and ongoing research provides part of the essential knowledge base required by the other two subareas.* Recent accomplishments include the development of the sequence

stratigraphic methodology for identifying sedimentary regimes, which provides a zero-order statement of bottom sediments in denied areas to support shallow-water ASW and mine-hunting operations; development of tripod design to measure sediment suspension for accurate surveys in the littorals, thus providing an effective and cost-efficient methodology to develop and test models for optical detection of mines; and development of techniques for combining light detection and ranging (LIDAR) bathymetry with hyperspectral images to infer bottom materials and depth, allowing airborne and satellite remote sensing estimation of bottom type and characterization in support of MCM and expeditionary warfare.

Budget information for Ocean Sciences research is provided in Table 4.9–1. Table 4.9–2 lists representative service interests in the three Ocean Sciences subareas. Representative basic research goals for Ocean Sciences in the near and far term are provided in Table 4.9–3.

Table 4.9–1. Basic Research Funding for Ocean Sciences ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601152N	Navy	0.5	0.5	0.6
PE 0601153N	Navy	92.0	89.4	97.6
Total		92.5	89.9	98.2

* Program Element names listed in Table 2–2.

Table 4.9–2. Service-Specific Interests and Commonality in Ocean Sciences

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td>Oceanography</td><td>None</td><td>Physical, chemical, biological, optical, modeling and prediction</td><td>None</td></tr>
<tr><td>Ocean Acoustics</td><td>None</td><td>Shallow-water acoustics
High-frequency acoustics
Long-range propagation
Acoustic reverberation</td><td>None</td></tr>
<tr><td rowspan="2">Ocean Geophysics</td><td>Logistics-over-the-shore (LOTS)
Coastal engineering
Coastal erosion</td><td>Continental terraces
Sediment processes</td><td rowspan="2">None</td></tr>
<tr><td colspan="2">Areas of Common Interest: near-shore/beach processes (A, N); coastal waves (A, N); coastal currents/water levels (A, N); coastal bathymetry (A, N)</td></tr>
</table>

Table 4.9–3. Representative Basic Research Goals in Ocean Sciences

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
Oceanography				
Special warfare Mine counter-measures Surveillance Navigation Amphibious landings	Sensors, Electronics, and Battlespace Environment Space Platforms	Littoral internal wave model Marine atmospheric sulfur model Channel optical scanner	Littoral ocean model Shipboard aerosol model Model to predict biology effects on optics and acoustics	Interactive open-ocean-littoral, air-sea model for physical, biological, chemical, or optical features
Ocean Acoustics				
Mine counter-measures Surveillance and reconnaissance Undersea warfare	Sensors, Electronics, and Battlespace Environment Space Platforms	Model effects of internal waves in shallow water Quantify fluctuations as function of propagation range	Littoral ambient noise model Quantified scattering mechanisms as function of frequency Improved acoustic tomography methods	Ocean bottom scattering model High-frequency propagation model in poro-elastic media
Ocean Geophysics				
Mine counter-measures Navigation Amphibious landings	Sensors, Electronics, and Battlespace Environment Space Platforms	Stratigraphic extrapolation model 2-D sediment entrainment model High-resolution littoral wind wave model Coupled wave-current model Improved sediment concentration sensors	Slope instability model 3-D bottom boundary layer model Littoral sediment transport model Broadband surf zone hydrodynamics model Coupled wave-current sediment model Near-shore sediment dynamics model	Predictive geologic model for shelf beach/bar morphology Sensor-driven model for coastal prediction Data-driven sediment dynamics model

4.10 Atmospheric and Space Sciences

Research in Atmospheric and Space Sciences develops the basic technical foundations in these areas for use in many applications important to DoD and other government agencies, including NASA, NOAA, and DOE. Research in meteorology (dynamical, physical, and modeling), space science (ground-, air-, and space-based), and remote sensing (active and passive) is conducted to support a broad range of DoD interests and activities. The products of these 6.1 basic research efforts and accompanying 6.2/6.3 work undergo transition to operational commands for use in weapon and surveillance platforms; planning of peacetime and warfighting operations; live and simulated training; and forecasting, mitigation, and modification of the battlespace environment.

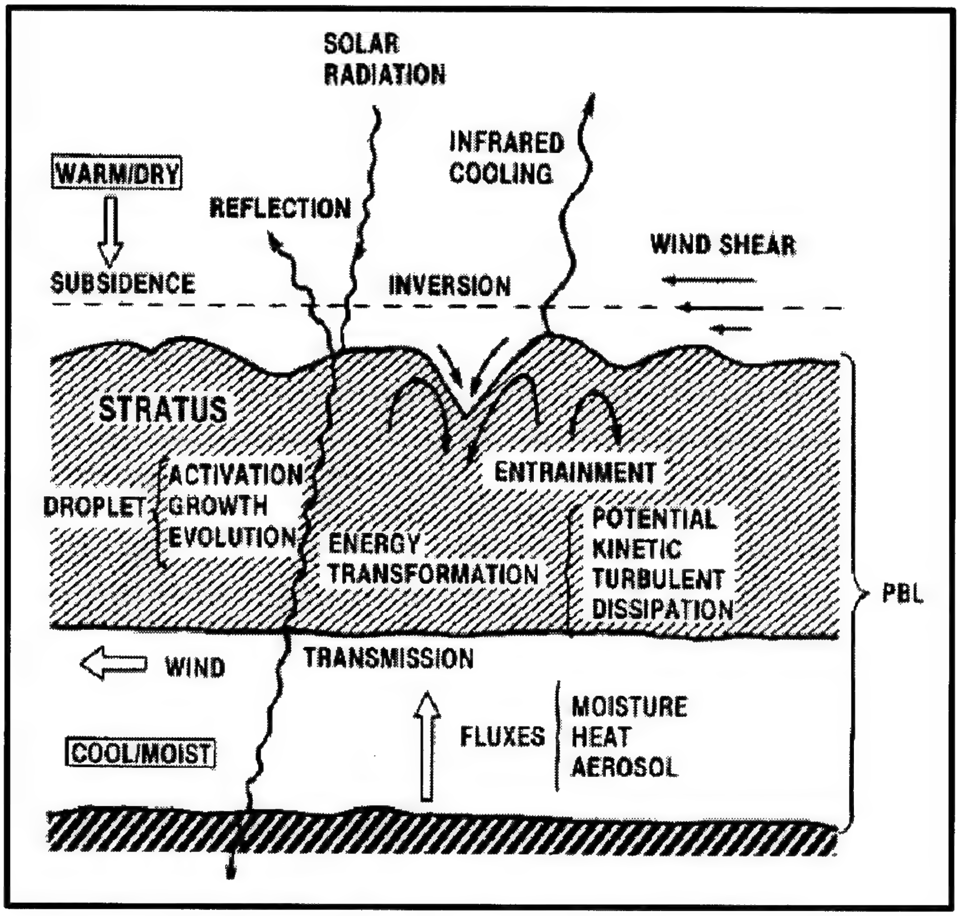


Figure 4–10. Marine Planetary Boundary Layer. The marine planetary boundary layer (PBL) is often capped by stratus clouds. The physical processes governing the breakup of stratus clouds are shown in the diagram. Above-cloud processes include wind shear, radiative cooling, and dry air subsidence. Within-cloud processes include droplet microphysics, turbulent dissipation, and energy transformations through latent heat. Below-cloud processes are dominated by the heat, moisture, aerosol, and momentum fluxes between the ocean surface and the atmosphere.

For DoD to plan and conduct a comprehensive program of research across the broad spectrum of air and space science topics, however, is fiscally and technically not feasible. Therefore, just as DoD provides products to other agencies, it is also dependent on others for support and collaborations. Examples of cost-sharing and leveraging of work by other agencies include tropical storm

research (ONR and NOAA), high-resolution modeling (ARO, ONR, AFOSR, NSF, and NOAA), atmospheric electricity (AFOSR and NASA), and boundary layer modeling (ARO and NOAA). In the international community, DoD sponsors scientific conferences such as the International Symposium on Spectral Sensing Research and the HITRAN Data Base Conference. These conferences attract government, university, and industry researchers from all over the world and help to ensure that this area of DoD basic research is highly leveraged and well-coordinated with others in the field.

As necessitated by mission assignments, each service has many specific areas of interest that serve as focal points for supported research. For example, the Army emphasizes tropospheric research in the area of boundary layer dynamics and remote sensing, including detection of chemical/biological warfare agents. The Navy has responsibility for global-scale meteorology focused on the marine environment, including tropical cyclones, marine cloud processes, air-sea interactions, and coastal zone predictions. Air Force weather research is more theater-scale over continental areas, with a concentration on providing smaller-spatial-scale predictions and increased timeliness of forecasts. The Navy space program emphasizes space-based exoatmospheric physics, while the Air Force counterpart tends to emphasize remote sensing of space objects, detection and tracking of missiles, and on-orbit satellite operations and survivability. In actuality, the distinctions among the services are often blurred. There are extensive inter-service collaborations and many complementary research programs.

Basic research in Atmospheric and Space Sciences includes work in three subareas:

Meteorology: In many military operations, weather determines the order of battle and meteorology is its associated force multiplier. Safety of operations, logistical planning and execution, deployment of forces in and out of theater, and sensor and weapon performance are all influenced by weather conditions. The DoD's atmospheric research effort seeks to provide the basic understandings of global and theater weather needed to construct reliable prediction models used by operational commands. Understanding the basic nature of atmospheric turbulence and cloud boundary layers affects the ability to predict the transport and diffusion of airborne effluents, aerosols, heat, and moisture. The ability to propagate a high-intensity laser through the atmosphere at a target is limited by our understanding and ability to compensate for natural and induced atmospheric turbulence. For blue-water operations, special attention is directed toward understanding the behavior and evolution of tropical cyclones in general and in the Western Pacific in particular, where DoD has the lead forecast responsibility for the United States. Plans are to improve our knowledge about motion (track), structure (size), and intensity (wind speed) of these important phenomena. The research program is designed to achieve an effective balance among theoretical modeling, analytical case studies, and experimental observations; increased attention is being given to the limits of forecast predictability. The overall goal of these research efforts is to provide the highest quality mission-tailored weather information, products, and services to our nation's combat forces in peace and war—anytime, anyplace.

Space Science: As demonstrated during Desert Shield, Desert Storm, and in current operations other than war (Bosnia and Iraq), U.S. forces are increasingly dependent on the capabilities of DoD space assets. GPS navigational capabilities, critical in high-technology warfare, are the direct result of long-term and ongoing basic research in precision timekeeping. Precision time-interval and time-transfer technology are also required for precise targeting and synchronization of secure communications and other systems. Ionospheric and upper atmospheric neutral density research will address needs for improved GPS accuracies, precision geolocation of RF emitters, and

RF communications. A new naval optical interferometer may provide positional accuracies of astronomical sources below the milliarc-second level. These advances, combined with improved astrometric reference frames and continuing improvements in compact electronics, will support operational requirements for systems with increased precision guidance and autonomous satellite navigation. The high bandwidth and secure communications features of the MILSTAR satellites are the result of large 6.1 investments in rad-hard electronics, broadband communications, ionospheric specification, and power generation. Continuing efforts in these areas, coupled with the Strategic Research Object in Mobile Wireless Band Communications, will result in a new generation of smaller, lighter, and more affordable satellites. The next generation and block upgrades of DoD missile early-warning satellites, Space-Based Infrared System (SBIRS), will not be possible without continuing investment in focal plane technology, onboard signal processing, and target/background phenomenolgy. Concurrently, the basic research community is already working to replace SBIRS with a new system of small satellites using adaptive hyperspectral sensing. These satellites will have even more demanding requirements for focal planes, signal processing capabilities, and the ability to acquire and track very dim targets against highly cluttered backgrounds. The potential ability to exploit basic understandings of plume signatures and varying background radiances in the design of spectrally agile electro-optical sensor systems may even enable the detection of cruise missiles from space-based platforms. Solar and heliospheric research is directed toward understanding the mechanisms for generation of solar extreme electro-magnetic fluxes, solar flares, coronal mass ejections, and the propagation of these phenomena from the sun through the magnetosphere and ionosphere. The resulting ionospheric variability affects RF communications over a very wide range of frequencies. A better understanding of solar and space physics, and the ability to predict sooner the effect of solar activity, will enable commanders to switch to other assets and to turn off those systems susceptible to damage, temporary or permanent, until the space environment has returned to acceptable limits. Upper atmospheric neutral density is also a function of solar activity, and future research will result in improved specification of satellite drag, orbital tracking, and vehicle reentry, providing U.S. Space Command greater capability to maintain and upgrade the Space Object Catalog.

Remote Sensing: Remote sensing characterizes environmental parameters and target signature characteristics critical to the performance of surveillance, acquisition, tracking, and home-to-kill sensors and weapons. It also supports critical needs in chemical/biological warfare. In meteorology, wind profiler technology will provide details regarding the fine structure of wind, temperature, humidity, and aerosols within the atmospheric boundary layer. Of special importance is the ability to model and predict marine refractivity profiles and surface base ducts. The development of the Airborne Laser is very dependent on basic research directed toward measuring and mitigating the effects of natural and induced atmospheric turbulence. Remote sensing for missile warning and subsequent track and kill will be greatly enhanced with the planned development of hyperspectral imagery techniques and associated automatic target recognition algorithms. The ability to use space-based electro-optical sensors to see through the lower atmosphere and clouds is increasingly important as the theater ballistic missile threat requires better all-weather capability and improved warning times for cueing tracking sensors. The threat of chemical and biological agents against military and civilian populations has led to increased emphasis on the development of biosensors with very specific responsivities.

Budget information for basic research work in Atmospheric and Space Sciences is given in Table 4.10–1. Service-specific interests and commonality in this area are presented in Table 4.10–2.

Representative research goals in Atmospheric and Space Sciences for both the near and far term are presented in Table 4.10–3.

Table 4.10–1. Basic Research Funding for Atmospheric and Space Sciences ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601102A	Army	6.8	4.9	5.8
PE 0601152N	Navy	0.1	0.1	0.1
PE 0601153N	Navy	22.6	22.0	24.0
PE 0601102F	Air Force	14.2	14.3	13.3
Total		43.7	41.3	43.2

* Program Element names listed in Table 2–2.

Table 4.10–2. Service-Specific Interests and Commonality in Atmospheric and Space Sciences

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Meteorology</td><td>Continental boundary layer
Small-scale meteorology
Transport, diffusion, obscuration
Chemical/biological defense</td><td>Marine boundary layer
Maritime and coastal meteorology
Heterogeneous flows
Major storms, worldwide
Synoptic to mesoscale modeling
Aerosol models</td><td>Upper troposphere
Mesoscale
Meteorology
Lightning</td></tr>
<tr><td colspan="3">Areas of Common Interest: aerosol effects (A, N); coherent structures (A, N); subgrid scale parameterization (A, N); large eddy simulation (A, N); atmospheric transmission (A, N, AF); radiative energy transfer (A, N, AF); nested models of all scales (A, N, AF); surface energy balance (A, N, AF); cloud formation and processes (N, AF); contrast transmission (A, N, AF); 4-D data assimilation (A, N, AF)</td></tr>
<tr><td rowspan="2">Remote Sensing</td><td>Fine resolution of wind, temperature, and humidity fields within boundary layer
Chemical/biological detection</td><td>Marine refractivity profiles</td><td>Surface-based ducts</td></tr>
<tr><td colspan="3">Areas of Common Interest: atmospheric profiles of temperature, humidity, winds, aerosol concentration (A, N, AF)</td></tr>
<tr><td rowspan="2">Space Science</td><td rowspan="2">None</td><td>Precision time
Space-based solar observation
Wave-particle interactions
Astrometry</td><td>Ground-based solar observations
Energetic solar events
Ionospheric structure and transport
Optical characterization</td></tr>
<tr><td colspan="2">Areas of Common Interest: neutral density (N, AF) ; ionospheric C^{3}I impacts (N, AF); celestial background (N, AF); geomagnetic activity (N, AF)</td></tr>
</table>

Table 4.10-3. Representative Basic Research Goals in Atmospheric and Space Sciences

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
		Meteorology		
Target acquisition battlefield forecasts	Sensors, Electronics, and Battlespace Environment	Lattice techniques for meteorological prediction	Improved algorithms for development and dissipation of transient cumulus clouds	Cloud and atmospheric electrification algorithms
Surveillance and precise targeting	Space Platforms	Understand coastally trapped disturbances Assimilation of remotely sensed physical parameters	Assimilation of tactical radar information Targeted weather observing strategies	Full 4-D data assimilation
Ship self-defense	Space Platforms	Improved air-sea transfer parameterizations incorporating wave interactions	Assimilation of remotely sensed marine boundary layer structures Spray aerosol generation models	Complete source/sink/advective marine aerosol models
		Remote Sensing		
C^3I, target acquisition, battlefield forecasts	Sensors, Electronics, and Battlespace Environment	Passive microwave synthetic aperture radiometry techniques	Accurate, high-altitude moisture sensors	Multispectral algorithms for 3-D structure of clouds
		Space Science		
Precise time, synchronization	Sensors, Electronics, and Battlespace Environment	3-nanosecond (ns) time transfer	1-ns time transfer, 3-ns synchronization	Sub-ns time transfer and synchronization
Astrometry for weapon guidance	Sensors, Electronics, and Battlespace Environment	10-milliarcsecond (mas) stellar position accuracies for 1,000 objects	3-mas accuracies; preliminary infrared catalog	Full stellar catalog at better than 1-mas maintainable accuracy
RF propagation through the ionosphere	Sensors, Electronics, and Battlespace Environment	New space-based sources of real-time ionospheric sensing	3x improved accuracies for precision geopositioning, GPS	Predictive models for ionospheric variability
Satellite drag and vehicle reentry	Sensors, Electronics, and Battlespace Environment	New database of and improved algorithms for neutral densities	3x improvement of satellite trajectories	Validated predictive models of neutral drag
Space-based solar observations	Sensors, Electronics, and Battlespace Environment	New physics models for flares, coronal mass ejections	200% improvement in predictions of C^4I outages	Full physics MHD for solar and geomagnetic disturbances

4.11 Biological Sciences

Research in the Biological Sciences provides the fundamental knowledge required to use biological processes and techniques for producing novel materials and processes having important military applications. Major goals are to increase affordability by reducing maintenance and synthetic processing costs, and to inhibit or prevent the deleterious effects of chemical, biological, and physical agents from interfering with military warfighting and peacekeeping operations by ensuring that safety standards are based on solid scientific evidence.

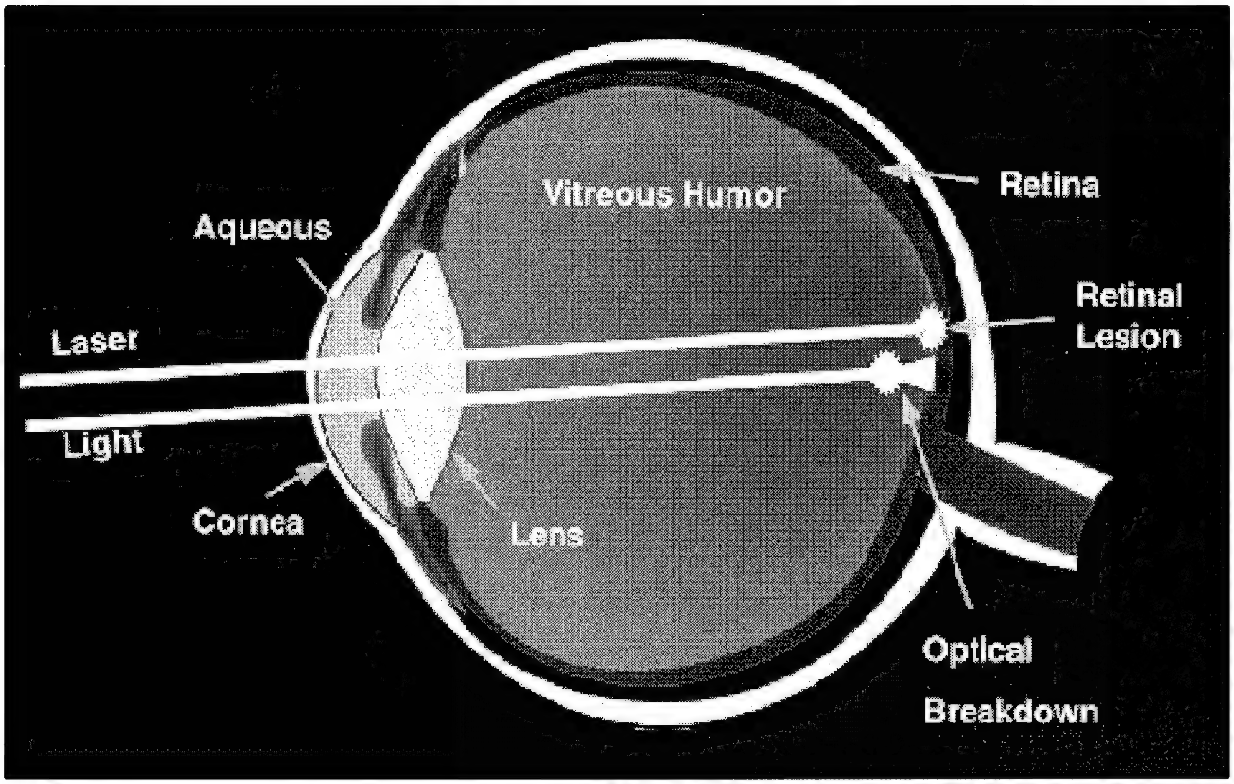


Figure 4–11. Laser Safety and Eye Protection for DoD Personnel. The Ultrashort Laser Pulse Bioeffects program of the Air Force aims to determine the maximum exposure limits of the retina for subnanosecond laser pulse durations. Goals are to understand the underlying biochemical and biophysical mechanisms leading to short- and long-term retinal injuries, and to develop theoretical models for extending ocular damage assessment to other frequency and pulsewidth regimes of importance to the military. The products of this research may be used to determine the retinal hazards of laser systems being developed or fielded by the military, to assess the impact of these hazards on combat mission performance, and to develop the appropriate laser protective eyewear.

With the exception of biomedical programs, which are closely coordinated through the ASBREM committee, a single service now conducts the basic research for all three services in areas where it is the technology leader for related 6.2 or 6.3 programs, or where that service has the largest investment and program expertise. The Army is the DoD executive manager for chemical and biological defense technology, and ONR and AFOSR rely on the results of Army-executed research in this area in meeting their own specific needs. The Air Force was designated through Reliance agreements to host the Tri-Service Toxicology Center at Armstrong Laboratory at Wright-Patterson AFB,

as well as co-located S&T programs in non-ionizing radiation and laser radiation bioeffects at Brooks AFB. The Navy is the only service that supports work in the marine environment.

DoD Basic Research Program activities in the Biological Sciences area comprise two major subareas:

Biotechnology: *Advances in biotechnology provide the warfighter with new options for increasing survivability and mission effectiveness on modern battlefields through novel materials, more sensitive and accurate sensors, and new techniques for protecting military personnel and materiel.* Current research programs in biotechnology focus on biomolecular processes and materials, biosensors, biodegradation, and biological transformations in marine environments. The Navy emphasis in this area is on molecular biology of marine organisms, biosensors for marine mine countermeasures and antisubmarine warfare, biodegradation in marine sediments, biofabrication, and bioadhesion. Army research in biotechnology focuses on improvements in military materiel and emphasizes research on cells as manufacturing plants, biocatalysis, cellular information processing, and biomolecular electronics and mechanics. In the common area of biomimetics, the Army program focuses on an understanding of biosynthetic pathways and the nature of materials produced by such biosynthesis and its exploitation via metabolic engineering. The Navy focuses on mimicking materials or processes that occur in marine organisms, metabolic engineering, genetic networks, cell-based sensors, and bioadhesives for underwater applications. The Air Force is investigating the biodegradation of toxic military compounds and, in the area of functional biomimetics, is studying animal infrared sensing systems and biomineralization processes as potential means for fabricating novel optoelectronic materials.

Cellular/Systems Biology: *The fundamental knowledge provided by research in this area will dramatically improve DoD's ability to reduce the hazards associated with the modern battlefield and peacekeeping operations and to provide efficient and effective combat casualty care when necessary.* Navy research programs target basic research that will lead to affordable technologies to support global fleet operations. Current Navy research programs in cellular/systems biology address engineered sonars based on the principles of marine mammals and bat sonar (biomimetic sonars), effects of low-frequency sound, immunophysiology, military operational medicine, and combat casualty care. Growth areas for the Navy address health issues in shipboard and submarine environments, biolocomotion, and diving physiology. Army research supports performance, sustainment, and adaptability of the soldier to changing, severe environments. The Army Medical Research and Materiel Command is responsible for major DoD research programs in combat maxillofacial care, heat strain physiology, military nutrition, and infectious diseases of military importance. The Air Force currently has mechanistic toxicology as its major focus for Biological Sciences basic research. Clarification of the basic mechanisms by which toxic chemicals and non-ionizing radiation cause biological effects will provide the basis for improved safety standards, resulting in less hazardous military operations. Air Force research programs in chronobiology are discussed under Cognitive and Neural Science (Section 4.12).

Budget information for Biological Sciences research is provided in Table 4.11–1. Table 4.11–2 identifies service-specific interests and commonality for this area. Representative basic research goals in the Biological Sciences for both the near and far term are provided in Table 4.11–3.

Table 4.11–1. Basic Research Funding for Biological Sciences ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	3.7	3.9	4.1
PE 0601102A	Army	23.9	23.4	25.6
PE 0601152N	Navy	1.4	1.4	1.5
PE 0601153N	Navy	27.4	26.6	29.0
PE 0601102F	Air Force	11.3	10.5	12.2
Total		67.7	65.8	72.4

* Program Element names listed in Table 2–2.

Table 4.11–2. Service-Specific Interests and Commonality in Biological Sciences

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Biotechnology
Biomolecular processes and materials
Biosensors
Biodegradation
Biodeterioration
Chemical and biological defense</td><td>Macromolecular structure and function
Antifungi
Nanoscale biomechanics
Biochemistry for CBW agent detection, protection, and decontamination</td><td>Marine biotechnology
Biofabrication
Underwater adhesion
Fast biosensor arrays</td><td>None</td></tr>
<tr><td colspan="3">Areas of Common Interest: biodegradation (A, N, AF); biocatalysis (A, N); biomimetics (A, N, AF)</td></tr>
<tr><td rowspan="2">Cellular/Systems Biology
Physiology
Toxicology
Biomedical</td><td>Sustainment, performance, and adaptations
Infectious diseases</td><td>Immunophysiology
Biomimetic sonar
Low-frequency sound
Military operational medicine</td><td rowspan="2">Toxic mechanisms
Non-ionizing radiation</td></tr>
<tr><td colspan="2">Areas of Common Interest: combat casualty care (A, N)</td></tr>
</table>

Table 4.11–3. Representative Basic Research Goals in Biological Sciences

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
Biotechnology				
Personal protection Cost-effective manufacturing	Human Systems Materials/Processes	Biomolecular materials via metabolic engineering	Bioengineered fibers and waterproof adhesives	Novel, multifunction low-observable composites
Mine detection	Sensors, Electronics, and Battlespace Environment	Biological chemo-sensing mechanisms	Exploitation of biomimetic sonar for acoustic detection	Combinatorial synthesis for multidetector arrays
Environmental quality	Materials/Processes	Tests for bio-availability of toxicants Ocean noise standards	Engineered biocatalysts for remediation Development of noise mitigation technology	"Mix and match" biodegradation for recalcitrant wastes Fleet implementation of noise mitigation technology
Biological threat detection	Chemical/Biological Defense and Nuclear	Biomolecular markers for threat agent interactions	Characterized signal transduction pathways	High-selectivity biodetectors
Cellular/Systems Biology				
Affordable, hazard-free operations	Human Systems	Validated laser safety standards to protect personnel	In vitro alternatives to animal testing (reduce time and cost 50%)	Computational alternative to in vitro tests
Combat casualty care	Biomedical	Combat resuscitation fluids	Freeze-dried blood products	Synthetic blood with high oxygen-carrying capacity

4.12 Cognitive and Neural Science

The DoD-wide program of research in Cognitive and Neural Science develops the science base enabling the optimization of the services' personnel resources. Areas of application include testing, training and simulation technologies, display support for target recognition and decision making, techniques to sustain human performance, human factors, and team/organizational design and evaluation methodologies. Joint agreements in 6.2/6.3 programs apply to manpower, personnel, and training issues. The defense-wide SPG in Cognitive and Neural Science has been responsive in aligning 6.1 programs in those areas. For example, the Navy has eliminated its psychometric program, relying on an Air Force investment. This shift enabled the Navy to reinforce its program on decision making in hierarchical teams and distributed expertise.

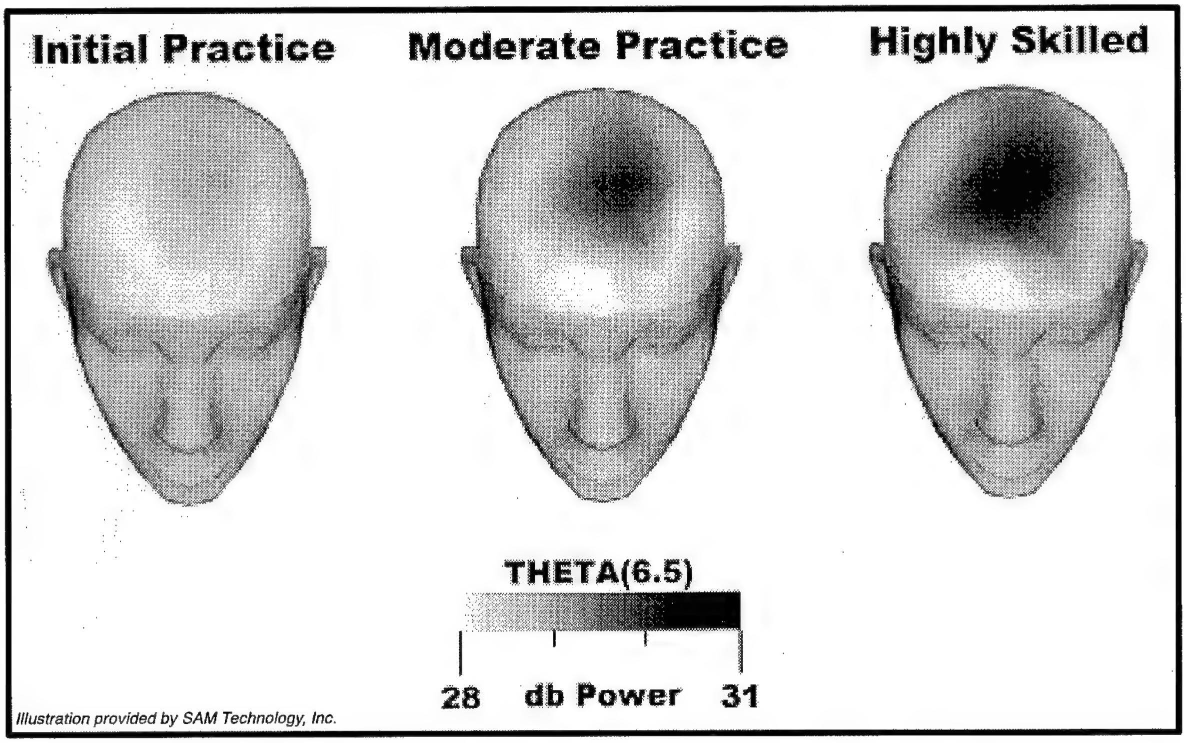


Figure 4–12. EEG Frontal Theta Band Activity of Focused Attention During a Working Memory Training Task. Electroencephalogram (EEG) brain activity can be used to distinguish individuals ranking high and low in working memory capacity and to distinguish high and low levels of mental effort.

DoD Basic Research Program activities in the Cognitive and Neural Science area involve two subareas:

Human Performance: *Research in human performance influences the services' approach to personnel selection, assignment, and training. It also explores ways to augment personnel performance in military environments and to develop new ways of organizing better, more effective teams and command and control organizations.* In general areas of common interest, the specific research efforts of the services are becoming more sharply defined. In research on teams and organizations, the Army concentrates on group processes, the Navy on coordination in distributed groups and models for evaluating organizational design, and the Air Force on communication strategies and

interfaces important to maintaining situational awareness. In the areas of cognition, learning, and memory, the Army concentrates on the discovery of training principles that underlie acquisition, retention, and transfer of soldier skills. The Navy emphasis is on artificial intelligence (AI)-based models of cognitive architecture. The Air Force focus is on intelligent tutoring systems and identifying individual differences in cognitive and psychomotor abilities.

In stress and performance research, the Army focuses on performance and psychological consequences of chronic physical and strong emotional stress. The Air Force program supports basic research on the circadian timing system—the biology underlying fatigue—including individual differences, performance prediction, and the brain processes involved in regulating adaptation to changes in state from sleep to waking to arousal. Electrophysiological measures of cognitive overload will provide new opportunities for human system interface technologies. The Army vision and audition program seeks to optimize the user interface in visual control of vehicles and reduce the effects of intense sound. Navy research focuses on teleoperated undersea requirements, automatic target recognition for precision strike missions, and auditory pattern recognition for sonar signal analysis. More generic principles of human image communication and sound localization are being investigated by the Air Force.

Reverse Engineering: *Reverse engineering research exploits the unique designs of biological neural systems by discovering novel information processing architectures and algorithms potentially implementable in engineered systems.* These efforts seek to imbue machine systems with capabilities for sensing, pattern recognition, learning, locomotion, manual dexterity, and adaptive control that approximate human functionality. The current Navy program in reverse engineering combines neurosciences and computational modeling in five topical areas:

- *Vision*—studies of primate visual processing pathways from retinal compression coding through extraction of color, shape, and motion from properties of recognized objects.
- *Touch/Manipulation*—studies of human and other primate tactile processing that underlies object recognition by touch and enables dexterous manipulation of small objects.
- *Locomotion*—studies of legged locomotion by insects and undulatory locomotion and maneuver by fish.
- *Biosonar*—studies of bat and dolphin active sonar processing for target detection, tracking, and classification.
- *Learning*—studies of various organisms' circuitry involved in conditioned response and associative learning.

The Air Force examines biological sensor system specificity and sensitivity to provide, for example, new technologies for ambient-temperature, lightweight, low-cost infrared sensors by examining the mechanisms used by animals to detect IR signals.

Budget figures for basic research work in Cognitive and Neural Science are given in Table 4.12–1. Table 4.12–2 provides an outline of service-specific interests and commonality in this area. Representative basic research goals for Cognitive and Neural Science in the near and far term are presented in Table 4.12–3.

Table 4.12–1. Basic Research Funding for Cognitive and Neural Science ($ millions)

Program Element*	Service/Agency	FY96	FY97	FY98
PE 0601101A	Army	0.1	0.1	0.0
PE 0601102A	Army	4.7	4.6	3.6
PE 0601152N	Navy	0.5	0.5	0.5
PE 0601153N	Navy	15.6	15.1	16.5
PE 0601102F	Air Force	10.3	11.3	14.0
Total		31.2	31.6	34.6

* Program Element names listed in Table 2–2.

Table 4.12–2. Service-Specific Interests and Commonality in Cognitive and Neural Science

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="2">Human Performance
Personnel selection
Training
Human system integration
Teams and organizations</td><td>Leadership
Motivation
Societal linkages</td><td>Tactile information processing
Sensory-guided motor control</td><td>Chronobiology
Neuropharmacology
Synthetic task environments</td></tr>
<tr><td colspan="3">Areas of Common Interest: teams and organizations (A, N, AF); cognition, learning, and memory (A, N, AF); stress and performance (A, AF); auditory and visual perception (A, N, AF)</td></tr>
<tr><td rowspan="2">Reverse Engineering
Machine vision
Autonomous vehicles
Automatic target recognition
Telerobotics</td><td rowspan="2">None</td><td>Autonomous undersea vehicle/manipulators
Neural computation plasticity
Automatic sonar classification</td><td>3-D audio displays
Infrared biosensors</td></tr>
<tr><td colspan="2">Areas of Common Interest: machine vision (N, AF)</td></tr>
</table>

Table 4.12–3. Representative Basic Research Goals in Cognitive and Neural Science

Area of Military Impact	Relevant DTAP(s)	Year 2000	Year 2005	Year 2010
		Human Performance		
Affordable, efficient training	Human Systems Information Systems Technology	Cognitive models validated	Curriculum authoring shells	Embedded training
Force leadership and troop morale	Human Systems Information Systems Technology	Conceptual model of leader-team performance	Model extended to commitment	Leader development program
Adaptive human–machine interfaces	Human Systems Information Systems Technology	Virtual reality workstations	Principles for visual environment and multimedia integration	Dynamically reconfigurable control centers
		Reverse Engineering		
Precision guidance and targeting	Human Systems Sensors, Electronics, and Battlespace Environment	Models of biological vision	Extrapolation to wideband and IR	Adaption of biological models to multispectral image analysis
Unmanned vehicles	Air Platforms Ground and Sea Vehicles	Adaptive control algorithms	Sensory-motor integration	Autonomous multi-functional robotics

5.0 SELECTED ACCOMPLISHMENTS

The development and sustainment of technologically superior military forces are dependent on having a strong and productive DoD Basic Research Program. The military services and defense agencies contract for and execute the program. It has had a far-ranging impact on many of the capabilities of our armed forces, as well as in everyday civilian life. For example, technical advances such as durable high-temperature engine materials, visual imaging, lasers, information processing, locating problem areas in aging aircraft, and global positioning have all been developed as a result of long-term and sustained investments in basic research. The time from research to field application typically takes from 7 to 20 years, depending on the nature of the discovery. It is possible, however, in areas such as software, theoretical models, and new processes (especially those for microelectronic materials and devices), to provide near-term payoffs, with fortuitous events yielding transitions to manufacturing and fielded systems in less than 7 years. Examples of such occurrences can be found in all twelve of the DoD basic research areas.

This section provides examples of more recent significant accomplishments of the Basic Research Program that offer both far-term and near-term military payoffs. They were selected on the basis of overcoming substantial technical challenges and the military importance of the accomplishments. The examples cited represent accomplishments of both extramural and intramural basic research in DoD, thus reflecting important contributions by the university community, in-house laboratories, and industry. Highlighted and briefly described are accomplishments on programs funded by the Army Research Office (ARO), the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR), the Defense Advanced Research Projects Agency (DARPA), and the Ballistic Missile Defense Organization (BMDO). These accomplishments provide a comprehensive sampling of the significant impact of basic research on the advancing capabilities or our armed forces.

5.1 Army Research Office

5.1.1 Performance Bounds for Automated Target Recognition

As part of the ARO Center for Imaging Sciences, principal investigators at Washington University have been quantifying the fundamental limits to the performance of automated target recognition systems in military scenarios. Recently they have been investigating the fundamental limits of estimating the position and orientation of targets given various sensors. Using a special measurement technique involving a Hilbert norm associated with the angle of view, they have developed a lower bound on estimating orientation of rigid targets for arbitrary sensors. This algorithm-independent bound provides a measure of resolvability of target parameters as a function of sensor data. This technique has been applied to the two-dimensional rotation group to determine the minimum expected error in estimating vehicle orientation for an arbitrary sensor at an arbitrary noise level.

5.1.2 Elimination of Optical Self-Focusing

Optical self-focusing causes high-power laser beams propagating through a medium such as air to break up into unpredictable distributions of hot spots and filaments. This severe beam distortion greatly limits applications of directed-energy weapons such as high-power lasers. The self-focusing phenomenon arises from the intensity-dependent refractive index of the medium.

Scientists at Stanford University have demonstrated a remarkable solution to this longstanding problem. They have shown that by simultaneously copropagating an additional "coupling" laser, the refractive index of the mixed medium can be tuned to 1.0, which eliminates self-focusing. The two laser beams must have frequencies that differ by a Raman resonance, and they must be of the appropriate intensity. The Stanford group initially demonstrated this effect in lead (Pb) vapor. The researchers plan to extend the technique to molecular systems at atmospheric pressures.

5.1.3 Coulomb-Blockaded Quantum Dots

The Army's interest in digitization of the battlefield drives the need for further miniaturization of electron devices. Before successful miniaturization can be achieved, an improved understanding of the operation of devices with nanoscale dimensions is needed. Electron transport through confined microstructures exhibits size effects, which arise due to the discrete nature of the electric charge and to the wave interference properties of quantum physics. As the device becomes electrically isolated, wave interference in these "quantum dots" leads to energy quantization and discrete isolated wave functions. In general, the spatial structure of these many electron state wave functions forms random patterns that are extremely sensitive to external perturbation of the electric or magnetic environment. Researchers at Stanford University have recently been successful in measuring electron transport through a single wave function in a micron-size quantum dot fabricated on a gallium arsenide (GaAs) heterostructure.

5.1.4 Infrared Imaging of In-Cylinder Engine Combustion Processes

A one-of-a-kind diagnostic tool for making in situ measurements of combustion events has been developed at Rutgers University. This high-speed, spectrally resolved, infrared imaging system is being used to obtain images of in-cylinder processes occurring in a diesel engine that was specially designed for infrared optical access. The Rutgers system is capable of capturing, simultaneously, four geometrically identical (pixel-to-pixel) images in four spectral bands at successive instants of time, at a rate of 2,000 images per second. Careful selection of the spectral bandpass characteristics allows isolation of regions dominated by either molecular radiation (e.g., water vapor or CO_2) or soot emission. A new spectral analysis method for processing measurements has also been developed. The four spectrally resolved images capturing the flow at an instant in time are simultaneously analyzed to yield quantitative maps of the combustion process. In particular, through appropriate selection of spectral intervals, it is possible to simultaneously image the distributions of temperature, water vapor, and soot.

Results achieved with the infrared imaging system and spectral analysis have yielded new insights into the reaction dynamics of the diesel fuel-injection spray plume. For the first time, researchers have been able to determine the temperature along the spray axis and demonstrate that the center of the spray is cooler than the outer regions. These and other results from the studies at Rutgers will be of great value in the development and validation of predictive models for diesel engine combustion.

5.1.5 Basic Science of and Database for Composite Reliability and Life Prediction

An investigation at the Naval Postgraduate School has resulted in the formulation of a probability distribution function that is capable of accurately characterizing the strength and life variability of composite designs. This accomplishment will enable researchers to establish reliability standards in production process control and life assurance of composite structures. The emphasis is to

incorporate physical processes and observations in the mathematical formulation of the distribution function. The fiber strength and durability (life under sustained load) are measured and characterized experimentally by a defect-based, multimodal, weakest-link model. The existence and the nature of the defects are identified by scanning microscopy of the failed samples from different modality regions. The fiber statistics model is then used to predict the probability of failure of the composite based on the underlying stochastic combinations of the sequential fiber failure processes. Extensive laboratory testing of single-fiber filaments and composites has provided experimental confirmations of the accuracy of the predicted composite strength from the fiber filament strength statistics. Hercules Inc. has used this probability model to eliminate sporadic composite strength variability in order to track graphite fiber production process control.

5.1.6 Vehicle Terrain Modeling

The force-projection warfighting concept relies on effective mobility operations on an extended battlefield. Improved modeling of the fundamental physics governing the complex interactions between vehicles and terrain during dynamic loading is needed to advance current empirical approaches to soil-tire and soil-track interaction. This work forms the basis for mobility prediction and also is required for training simulation and virtual prototyping of vehicle mobility in the synthetic environment.

Toward this end, researchers at Kansas State University recently developed a mathematically rigorous approach to the challenging problem of modeling vehicle-terrain interaction. In this formulation, the most influential parameters of the contact interaction (i.e., body geometry, deformation) are simultaneously accounted for, and the contact properties are determined based on readily measurable quantities. This effort demonstrated the application of contact mechanics to the general problem and developed a first-generation model for tire-soil interaction. Future work is aimed at developing and validating nonlinear, three-dimensional models of interaction phenomena between a vehicle's running gear (tire or track) and the terrain (soil or snow).

5.1.7 Mass Bleed Effects on Supersonic Base Flows

Small amounts of mass are frequently ejected into the base region of Army projectiles in flight to reduce drag; however, because the physics underlying the subsequent base drag reduction are unknown, the amount and rate of mass ejection must be determined empirically. Experiments were recently performed at the University of Illinois to investigate the effects of base bleed on the fluid dynamic interactions in the near wake of a cylindrical afterbody in Mach 2.5 flow. Detailed mean velocity and turbulence measurements have been obtained in the entire near-wake region at three different bleed rates. The three cases studied provide insight into the near-wake fluid dynamic interactions produced by widely varying bleed conditions. The net benefits of base bleed are maximized at conditions that correspond to the highest base pressure, the disappearance of the primary recirculation region, and the lowest turbulence and entrainment levels in the near-wake flowfield. Use of larger bleed orifices, porous bases, or bleed orifices located along the outer base annulus is suggested for maximizing the benefits from base bleed.

5.1.8 Laser-Assisted Identification of Biological Aerosols

Detection and identification of biological aerosols in situ or at a distance are profound problems affecting protection of soldiers in the battlefield as well as civilian populations exposed to accidental releases of bioaerosols. Fluorescence of biological particles in ultraviolet light has been an

identifying, but not complete, characteristic of biological aerosols. Yale University has worked with Army Research Laboratory scientists to develop a unique prototype instrument for in situ identification of individual biological aerosols. The device uses a solid-state infrared laser to measure the aerosols drawn into a sampling chamber. Aerosol particles greater than a given size are immediately illuminated by an ultraviolet laser. The elastic scattering and fluorescence spectra from the aerosol are measured and compared with known biological aerosol signatures.

5.1.9 Low-Cost Joining Method for Composites

A new joining technique, called diffusion-enhanced adhesion, has been developed at the University of Delaware for bonding dissimilar materials. It involves the use of an amorphous thermoplastic bonding interlayer that is co-molded with a semicrystalline thermoplastic, such as polyphenylsulfone (PPS), in combination with a compatible epoxy adhesive. The epoxy diffuses into the amorphous layer and creates an interphase region that is capable of bonding two bulk layers together before the epoxy cures and diffusion stops. The technique provides an affordable, low-pressure, low-temperature joining process that offers reduced tooling and assembly costs for many structural materials and applications. This process has recently undergone transition to United Defense Limited Partnership, where it has been used to bond a thermoplastic sponson to a thermoset composite lower tub on the composite armored vehicle (CAV).

5.1.10 Superconducting Magnets for Portable Power Generation and Imaging

Recent work at the University of Houston has resulted in two remarkable advances in the development of flux-trapped superconducting magnets. Researchers have trapped record magnetic fields of 10T in melt-textured YBCO superconducting oxide ceramics. These fields are six times greater than those produced by state-of-the-art NdFeB permanent magnets. The fields are trapped in the magnet through the formation of a dense array of pinning centers, which are formed by irradiating the samples with 200-Mev protons. Usually these fields suffer a gradual reduction in strength (flux creep) over time. However, the Houston team has also developed a post-activation cooling procedure that virtually eliminates this form of degradation. The advances are expected to lead to new generations of extremely compact Army systems, including very small megawatt generators and field-portable magnetic resonance (medical) imagers.

5.1.11 Novel Families of Glassy Alloys

Glassy metallic alloys and composites offer high strength-to-weight ratios, net-shape formability, tailored dielectric properties, and unusually high elastic-energy storage. Several families of multicomponent alloys have been identified that are capable of forming metallic glasses under cooling rates of less than 1000 K/s and as low as 1 K/s. This opens up the possibility of producing these materials in bulk using conventional casting methods.

This project is being sponsored jointly by the Army and Air Force at the California Institute of Technology to study the processing and fabrication of bulk metallic glass composites. It focuses on high-strength aluminum and titanium quaternary and quintary alloys reinforced with silicon carbide (SiC) fibrils. Net-shape casting of an electronic chassis for avionics is expected in the near term, with far-term projections for lightweight structures (e.g., composite materials for aircraft and land vehicles).

5.2 Office of Naval Research

5.2.1 Static Random Access Memory

A transistorless static random access memory (TSRAM) was first demonstrated in January 1996 at the California Institute of Technology. It is expected to be about 100 times smaller, 10 times faster, and much cheaper than SRAMs, which it will eventually replace. It will also be about one-tenth the size and less than half the cost of the dynamic RAMs (DRAMs) used in computers today. The TSRAM is expected to be inherently far more tolerant to radiation than either SRAMs or DRAMs.

5.2.2 New Low-Power Laser

A new laser has recently been demonstrated under research performed at the University of Southern California. This solid-state injection laser has a threshold current of 3 micro-amperes—about 1,000 times lower than previously demonstrated. Its power consumption for minimum discernable output signal is 100,000 times less than that of previous lasers. For the first time, a laser has been demonstrated that requires far less power than a typical large-scale silicon integrated circuit. This will enable chip-to-chip optical dissemination of signals in a computer. The operating speed of a computer will no longer be limited by the transit time and dispersion of copper wires.

5.2.3 Magnetic Materials for Solid-State Microwave Devices

Spinel ferrite thin films can be substituted for bulk magnetic components in microwave devices for improved producibility and robustness. In these ferrites, it is the site distribution and valence distribution of the metallic cations that determine the material's magnetic and electronic properties. The development of ferrite film technology for microwave nonreciprocal devices (e.g., circulators), especially the reduction of losses, requires that these distributions be determined for films grown by different techniques. The Naval Research Laboratory, using extended x-ray absorption fine-structure measurements together with theoretical multiple scattering calculations, has for the first time provided the necessary structural information for a series of spin-spray-grown nickel zinc (NiZn) ferrite films. In all samples, the nickel ions reside on octahedral sites and the zinc ions on tetrahedral sites. The iron ions reside on both sets of sites in a ratio determined by the relative concentration of zinc to iron; addition of small amounts of zinc forces a larger fraction of iron cations into the octahedral sites, thereby increasing the magnetization. At higher zinc concentrations, local lattice distortions cause the magnetization to decrease. These materials offer a new opportunity for defense electronics in which the radiofrequency circulators required for transmit-receive modules will be incorporated directly into the solid-state device rather than as separate ferrite components literally cemented into the system, thereby achieving cost savings and greater mechanical and electrical reliability.

5.2.4 Adaptive Retina-Like Preprocessing for Imaging Detector Arrays

Neurocomputational techniques known to exist in biological vision have been investigated as a way to improve the performance of electronic imaging arrays. Scientists analyzed retina-like algorithms derived from existing studies of biological visual systems and extended them to infrared imaging arrays. Results from these studies included demonstration of real-time adaptive nonuniformity correction with an infrared focal plane array, simulation of on-chip algorithms for enhanced signal-to-noise ratio, and simulation of three-color IR imagery and associated neuroprocessing.

Navy systems should benefit from a new ability to use infrared focal plane array technology in harsh optical conditions.

5.2.5 Shallow-Water Buried Mine Detection

A powerful technique that addresses the difficult problem of buried mine detection and identification has been developed by a team consisting of university and industrial researchers. The technique involves ensonification of buried objects with simulated dolphin clicks and fusion of the output of two neural network classifiers—one responding to the time-domain information in the signal and the other to frequency-domain information. The technique achieves greater than 97 percent detection with very low false alarm rates with manmade objects buried under about 6 inches of sediment at uncertain locations and aspect, and in the face of significant clutter. This result is far superior to that achieved to date with alternative technologies.

5.2.6 Thermoelectric Technology Advances

The Navy supports a multidisciplinary research effort in the field of thermoelectric materials, focusing on theory, experiment, and analysis. Recent results include identification of new materials and systems that demonstrate between 50 percent and 400 percent improvement in some key properties. Theory has specifically identified opportunities in thin-film structures that could improve thermoelectric performance by at least a factor of four, and results of this work have already led to the development of whole new classes of compounds.

5.2.7 Nonlinear Polymer Investigations Under Precision Strike Navigator Project

The synthesis and characterization of new nonlinear optical polymers is leading to improved figures of merit for active and passive optical waveguides useful for high-speed optical analog-to-digital converters, 100-GHz modulators, and switches. Areas of potential high impact are high-speed optical signal processing applications, such as photonic control of phased-array radar and real-time microwave antenna datalinks. An immediate transition for polymer program technology is a 6.3 advanced technology demonstration of a polymer waveguide containing optical polarizer and phase modulator functions integrated on a silicon semiconductor for ultimate use in a fiber-optic gyroscopic navigation unit, called the Precision Strike Navigator. A key demonstration this year proved that an electro-optic film could be processed for integration on a semiconductor chip without the need for high-temperature electric-field poling, which has implications for low-cost mass production on 6-inch wafers.

5.2.8 Prediction and Improvement of Weld Integrity

As part of an effort to predict microstructure and properties of steel weldments, scientists at the Naval Research Laboratory, in conjunction with Cambridge University in England, have successfully simulated the evolution of microstructure and resultant hardness of welds in HSLA–100 (a high-strength steel that has found widespread naval use). Using dilatometer measurements and extensive transmission electron microscopy to determine volume fractions of martensite and other microstructural constituents, the researchers validated results of the computer simulations experimentally. The experiments, conducted over a broad spectrum of temperatures and cooling rates, are expected to be of particular importance to the increased use of HSLA–100 steels in future Navy ships and submarines, where assurance of structural integrity depends on avoiding hydrogen cracking, and enhanced affordability depends on minimizing heat inputs during welding.

5.2.9 New Piezoelectric Materials for Sonar and Other Applications

Composite piezoelectric materials, made by combining a piezoelectric ceramic with a passive polymer, are emerging from a long-term, ONR-sponsored program at Pennsylvania State University. By tailoring the microstructure of the piezocomposite to a specific application, a materials engineer can ensure the maximum coupling between the piezoelectric phase (where the electromechanical energy conversion takes place) and the sound field to be generated or detected. For pulse-echo imaging transducers, one to three piezocomposites (plates consisting of long, thin rods of piezoceramic held parallel to each other and perpendicular to the plate face by a passive polymer matrix) offer superior performance to the conventional piezoceramic designs in sensitivity, pulse compactness, and noise levels. Practical applications of this technology are expected for diver-held imaging sonar used in the classification and clearance of undersea explosive mines.

5.2.10 Ceramic Composites for Severe High-Temperature Applications

As part of the ONR High-Temperature Program—a combined effort of national laboratories (LANL, NASA–LeRC, NRL), universities (Purdue, SUNY, New Mexico Tech), and industry (Pratt & Whitney)—a promising composite material, $MoSi_2$–Si_3N_4, has been introduced that has capabilities beyond the reach of current superalloys. These composites have comparable oxidation, creep, toughness, and wear properties to ceramics, but with superior ductility and impact properties. These properties are attributed to the $MoSi_2$ crystal structure that has a combination of metallic and covalent bonds. As an example, the metallic bonds of the crystal provide high thermal conductivity and plasticity, and the covalent bonds contribute to creep, oxidation, and wear resistance. These alloys are made by consolidating the fine powders, followed by sintering and hot-isostatic pressing processes that combine both the metallurgy and ceramic fields. Pratt & Whitney has recently successfully tested a blade-outer-air-sea (BOAS) prototype component made from this composite as part of the IHPTET program.

5.2.11 Arctic Climate Observations Using Underwater Sound

In December 1994, the United States and Russia signed a bilateral agreement for joint research in acoustic thermometry to be conducted as part of the Joint U.S./Russia S&T Cooperative Research Program. Researchers are using measurements of the travel times of acoustic signals propagated across the Arctic Ocean to measure changes in temperature. Results of a pilot experiment detected large temperature variations in the Arctic Ocean with significant warming at depths of 200–700 meters, corresponding to Atlantic water inflow. Confirmed by subsequent icebreaker and submarine cruises (the ONR-funded work), these observations are revising our understanding of the Arctic Ocean as one that is more dynamic than previously thought. These experiments provide further insight on global climate change, Arctic Ocean circulation, and long-range underwater acoustic propagation.

5.3 Air Force Office of Scientific Research

5.3.1 Better Understanding of Fluid-Structure Interaction Through Improved Algorithms

Research at Duke University over the last six years has led to the development of an efficient algorithm for studying the interactions between aerospace structures and the surrounding airflow, also known as fluid-structure interaction. This new algorithm will lead to an increased physical

understanding of flutter associated with aircraft wings and compressor blades in gas-turbine engines, and useful models for the study of active control and optimal flexible airfoil design. The algorithm has already had practical and analytical military and civilian applications. For example, Air Force researchers at the Flight Dynamics Directorate of Wright Laboratory are incorporating this methodology into their analytical tool box to better understand the behavior of flexible, composite wings. Engineers at Pratt & Whitney also use the technique to improve the design of compressor blades in gas-turbine jet engines.

5.3.2 Extended Resistance to Wear and Corrosion Through Superhard Crystalline Material

In 1989, theorists suggested that a hypothetical compound, crystalline carbon nitride (b–C_3N_4), could be developed with a hardness comparable to diamond. Such a material would be in great demand because wear and corrosion currently cost industry and consumers more than $200 billion annually. Many research teams around the world have been trying to produce this composite in the laboratory, but none have been able to achieve a material with sufficient hardness for industrial coating applications.

Recently, however, three Northwestern University scientists created a superhard material second only to diamond in hardness. This breakthrough is a result of research on polycrystalline nanolayered superlattices that has been ongoing at Northwestern for several years. The new material, a fully crystalline composite coating containing carbon nitride layers, has a wide variety of military and civilian industrial applications as a coating for surfaces and devices requiring exceptional protection against wear and corrosion. Specific Air Force applications include coatings for bearings, aircraft landing gear, and onboard electronic devices.

5.3.3 Demonstration of Link Between Brain Signals and Learning Skills

Preliminary findings by basic researchers in industry suggest that electrical brain signals are related to human learning. In a series of experiments, investigators at SAM Technology and EEG Systems Laboratory demonstrated that learning-related changes in brain signals are reproducible and similar across tasks and subjects. (See Section 4.12, Cognitive and Neural Science.) These results support conjecture that individuals acquire skills by developing an enhanced ability to concentrate attention on the higher-order or “strategic” aspects of a task while automating the lower-order or “routine” aspects. These findings may increase training effectiveness and reduce training time by allowing a more precise determination of when a skill has become automatic. This result has potential for application in a number of Air Force training situations for pilots and various types of technical personnel, including computer and electronics system specialists.

A U.S. patent has been issued for this research. The patent covers the use of brain measures to index the level of mental effort and focused attention needed to use adaptive computer interfaces, such as those found in computer-aided instructional systems. These findings will enable a new generation of “sympathetic” intelligent tutoring systems and realistic training simulators that will be able to adapt training in order to optimize the trainee’s concentration and thus decrease training time.

5.3.4 Improved Modeling of Radio Communications Through High-Temperature Ion Chemistry

Researchers at the Phillips Laboratory’s Geophysics Directorate recently demonstrated the world’s first apparatus for studying ion-molecule reactions at temperatures up to 1800 K—twice as

high as the existing laboratory device measurement limit. The High-Temperature Flowing Afterglow (HFTA) device can make detailed measurements of the reactions of ions at high temperatures, which can affect radiowave propagation. Application of this technology will improve the Air Force's ability to accurately pinpoint the location of missiles, rockets, and future hypersonic vehicles in space and to maintain constant communications with these vehicles. It will also lead to improved models used to calculate their radar cross sections.

5.3.5 Discovery of Gene Involved in Memory Formation

A research team at the University of Houston has recently discovered and sequenced a gene that may play a role in regulating and then stabilizing structural changes that take place within the central nervous system as memories are consolidated. This exciting and potentially very important finding about the mechanics underlying memory formation will contribute significantly to the eventual understanding of how best to design training and operational procedures that will enable Air Force personnel to learn more efficiently and fight more effectively.

The Air Force mission calls for continuous operations and constant transmeridian travel by air and ground crews. However, related physiological and psychological stresses can cause dangerous mistakes, particularly in tasks that require judgment. Understanding brain mechanisms underlying performance, including the action of memory formation, will allow better design of operational and training procedures. These advances will provide Air Force decision makers with greater flexibility in modulating responses to global, regional, or local situations while also controlling risk.

5.3.6 Improved Performance in FET Electronics

Researchers at the University of California at Santa Barbara (UCSB) have developed a new design for the field effect transistor (FET), a common component of military and civilian electronic circuits. The new FET exhibits an extremely low phase noise—essential to the development of oscillator circuits and systems with expanded sensitivity and wider useful operating range. This accomplishment will provide significant performance improvements for many types of Air Force systems, including airborne radar, communications, and electronic warfare systems.

Reduced phase noise is possible because of a thin surface layer of aluminum gallium arsenide (AlGaAs), which is deposited on the FET at extremely low temperatures. Research into the preparation and use of low-temperature AlGaAs and related materials has been ongoing since 1990. The work at UCSB is being accomplished under the new Program for Research Excellence and Transitioning (PRET). PRET was established to facilitate the rapid transitioning of university research to the defense industry. Hughes Research Laboratory is also an active participant in this effort.

5.3.7 Nondestructive Evaluation of Aircraft Using "Dial-a-Depth" Technique Structures

Multidisciplinary research at Vanderbilt University has led to a new technique for detecting flaws as a function of depth in metallic structures. This new instrument is a key advance in the technology for selectively detecting cracks adjacent to rivets in model aluminum specimens of aircraft lap joints. Funded by AFOSR for several years, the team has achieved a research advance that responds directly to an urgent Air Force logistics community need for new nondestructive evaluation (NDE) technologies to inspect the service's aging fleet of aircraft.

The patented methodology uses a rotatable-multiwire, eddy-current induction sheet placed between a superconducting magnetic gradiometer and the lap-joint specimen. The gradiometer has

extreme sensitivity to magnetic field changes and can detect cracks at a greater depth than ever before—even beyond 1/4 inch. The technology can also selectively detect cracks at different depths in the lap joint. In earlier studies, a less sophisticated arrangement barely allowed the detection of second-layer cracks, which could go undetected if first-layer cracks or other structural anomalies were in the vicinity and closer to the surface. Now, by adjusting the phase of the magnetic signal received, it is possible to observe the effect of a second-layer crack quite easily, while a nearby first-layer crack makes little or no contribution to the recorded signal. The technology can also reveal third-layer cracks as well as corrosion between layers. Though still in the laboratory stage, this NDE technique promises to be very effective in discriminating deep cracks and corrosion in aircraft.

5.3.8 Improved Material Production for Electronics and Electro-Optics

An investigator at the University of Southern California (USC) recently devised a technique for solving a 40-year-old problem regarding the behavior of ferroelectric materials. Widely used in modern electronics and electro-optics, ferroelectric materials possess strong internal electric fields that have highly attractive electronic properties. The novel nonlinear optical technique developed at USC provides a real-time, nondestructive means for visualizing ferroelectric material processing. The technique will enable significant improvements in the performance of materials used in Air Force radar and broadband communications systems. It could also lead to advances in countermeasure applications such as transforming laser wavelengths to the infrared region. This nonlinear optical technique involves amplification or attenuation of one laser beam with respect to another. It provides a real-time, nondestructive means for visualizing (i.e., making movies of) electric dipole alignment (analogous to magnetic domains of better known ferromagnetic materials). This capability will enable domain wall motion, as well as the outcome of poling, to be nondestructively measured and studied—leading to better poling procedures and better material performance in the future.

5.3.9 Using Ionized Gas To Clean Electronic Circuit Boards

March Instruments, Inc., a small business supplier of processing and test equipment to the electronics industry, will design and manufacture a new system to rapidly and efficiently clean electronic printed circuit boards using hot plasma (ionized gases). The system is based on a licensing agreement signed with the University of Tennessee (UT) to transfer AFOSR-sponsored university research accomplishments involving the efficient generation of steady-state plasmas under normal atmospheric pressure conditions. The technique developed at UT has significant advantages over current systems. It is anticipated that the new ionized gas cleaning system will reduce the cost of ultrafine cleaning of electronic circuit boards—an essential step in their manufacture—by a factor of 10. Over time, this accomplishment will also help to reduce the cost of Air Force and civilian electronics systems.

5.3.10 Predicting Failure Initiation in Composite Materials and Multimaterial Interfaces

A researcher at Washington University in St. Louis has developed an improved computational method for predicting failure initiation in composite materials and multimaterial interfaces. Previous methods have used finite element-based formulations, but they suffer from severe inaccuracies—differing by as much as an order of magnitude from analytical predictions. The new technique, a modified Steklov method, offers greater accuracy, reliability, and speed (up to 100 times faster) for predicting failures in onboard electronic components, adhesively bonded joints, and

laminated composites. Engineers will be better equipped to interpret test data, rank the expected durability of alternative designs, and develop more reliable multimaterial joints. This capability is crucial for evaluating practical designs, where a structure or component could contain hundreds or thousands of stress concentrations requiring characterization.

Rapid transition of the new computational methodology to Rome Laboratory will aid Air Force efforts to enhance the performance and reliability of multichip electronic modules, such as those used extensively in the F–22.

5.3.11 Improved Global Cloud Forecasts

Researchers at Florida State University are investigating explicit modeling of cloud processes and its impact on global cloud prediction models. They are using data from the Air Force's Real Time Nephanalysis (RTNEPH) global cloud database, along with satellite-based measurements of the earth's outgoing long-wave energy and total precipitable water, to determine their relationship to profiles of atmospheric humidity. Early results indicate that this method improves global cloud cover forecasts, especially in tropical regions where conventional weather observations are sparse. Improvements to cloud modeling will significantly enhance the Air Force's ability to anticipate and exploit meteorological conditions to help meet mission requirements.

5.3.12 Improved Design and Performance of Military Systems Through Algorithms

Applied mathematicians working at the Virginia Polytechnic Institute and State University's DoD–URI Center for Optimal Design and Control have developed a new, fast algorithm for improving the design and performance of existing and future military systems. A multidisciplinary team composed of specialists in distributed parameter control, guidance, fluid mechanics, optimization, and computational mathematics has been working on this problem. Their new methodology builds on a solid foundation of AFOSR-sponsored research in distributed parameter control and computational mathematics over the last decade. The method has already been tested successfully on a wide variety of Air Force systems, including jet engine inlet design, nozzle design, and aeroelastic tailoring to enhance aircraft lifespans. This new mathematical tool has a multitude of potential DoD applications, such as wing-body design and optimization, flow tailoring for improved performance, propulsion system design, and multidisciplinary design optimization of aircraft. Many nonmilitary applications, such as improved design and function of inkjet printers, are also possible.

The new approach shows great promise as an effective means for eliminating the need to compute mesh sensitivities for gradient-based aerodynamic design applications. Meshing can account for as much as 90 percent of the design cycle and computational time in three-dimensional flows. The new algorithm is a sensitivity equation method based on partial differential equations that define flow sensitivities. The sensitivity equations are used as a guide in developing and selecting efficient computational methods for approximating sensitivities and the corresponding gradients. The algorithm combines robust optimization with carefully chosen numerical schemes. This approach has reduced design cycle times by as much as an order of magnitude in certain nozzle design applications.

5.4 Defense Advanced Research Projects Agency

5.4.1 Reusable Fuel Cells To Replace Disposable Batteries

Batteries used to provide power for a variety of portable military equipment are the bane of most soldiers' existence: They are too big, they weigh too much, they do not last very long, they are expensive, and their disposal raises environmental and logistics issues. DARPA, in collaboration with the Army Research Office, has recently demonstrated a prototype fuel cell designed to replace, in many applications, a popular military standard battery. The target application is the Army's BA–5590 primary lithium battery, which can provide 50 watts of power. (The Army purchases approximately 350,000 of these single-use, disposable batteries annually at a cost of $100 each, including about $30 for disposal). The replacement solid polymer electrolyte fuel cell uses hydrogen as a fuel (from a rechargeable metal hydride source) and oxygen from the air to produce electricity in a system packaged into a BA–5590 battery box. These fuel cells can be reused hundreds of times by simply recharging or replacing the hydride cartridge. Mission weight savings of factors of ten or more are projected.

The prototype fuel cell has been tested in all orientations and under a limited range of adverse weather conditions with excellent results. It received an enthusiastic response when operated for Army senior management. Field trials are pending. This unit is the first demonstration from DARPA's portable power initiative, which also includes research on fuel cells powered by liquid fuels as well as other advanced energy-conversion concepts.

5.4.2 Magnetic Materials and Devices

DARPA's Magnetic Materials and Devices Program has developed extremely sensitive magnetic field sensor chips. These sensors are the first to integrate giant magneto-resistance (GMR) multilayer films with linear integrated circuits to provide a digital output. Similar sensor chips can be used for many military and commercial applications, such as vehicle and other ferromagnetic body detection, measurements of linear motion, precision dial gauge metrology, and current sensing. The program is also developing radiation-hardened, nonvolatile memory based on GMR and related spin-dependent transport phenomena. This memory is expected to be competitive with semiconductor memory early in the next decade.

During the past year, two versions of the magnetic sensors have been demonstrated. The first sensor was originally designed to sense the minute variations in magnetic field caused by the rotation of an engine crankshaft to allow better engine control. DARPA researchers have found that the same sensor can also be used to monitor the turning of a gear by sensing the presence or absence of a gear tooth. A second GMR sensor has been developed that can sense the motion of a rifle at 15–20 feet. The next generation of the sensor is expected to increase this detection range to more than 100 feet.

5.4.3 Red Blood Cell Heteropolymer

Researchers supported by DARPA's Biological Warfare Defense Program have demonstrated the capability to decrease rapidly—by a factor of up to a million—the amount of virus circulating in a monkey's bloodstream. Key to this accomplishment was the development of special double-ended heteropolymer (HP) molecules that bind to monkey red blood cells on one end and the targeted virus on the other. When a monkey is injected intravenously with the HP molecules, the molecules bind to normal red blood cells.

In laboratory tests on monkeys injected with the virus for which the HP molecules were specific, the modified red blood cells were able to reduce the level of virus in the blood stream by four to six orders of magnitude (log units) in less than 1 hour. The modified red blood cells retain this level of virus-clearing capability for over 5 days after a single intravenous injection. This demonstration represents a very significant first step toward providing internal protection to the warfighter against agents that might be used in biological warfare.

5.4.4 Advanced Microelectronic Circuit Integrating Resonant Tunneling Diodes

To enhance the overall performance of electronic circuits, researchers supported by DARPA have been investigating approaches for combining advanced electronic device technologies with conventional electronics. This work has recently led to a successful demonstration of the world's first integration process combining compound semiconductor (type III–V) indium phosphide (InP)-based heterojunction field effect transistors (HFETs) with novel resonant tunneling diodes (RTDs) exhibiting two different current-voltage response curves: single peak and four peak. The integration of conventional devices with these quantum RTD devices to achieve increased overall functionality with a reduced number of devices was demonstrated in an integrated circuit with a seven-state transfer function forming the core circuit for a redundant-digit, carry-free adder. Significant improvements in speed (1 volt/picosecond at milliwatt level), density, and low power (1 volt/microsecond at nanowatt level) for microelectronics were achieved. Processes are now available for the monolithic integration of RTDs and III–V transistors at the 1,000 transistor/RTD level. This level of complexity enables near-term development of system components important to many DoD applications, such as wideband analog-to-digital converters, data demultiplexors, memory FIFOs/caches, digital filters, and low-power on-chip and interchip optical communication links.

Related research is focused on integrating compound semiconductor RTDs with conventional silicon complementary metal oxide semiconductor (CMOS) circuitry, an important step toward developing silicon-based quantum metal oxide semiconductor (MOS) technology. An innovative technique for digital logic design using RTDs in conjunction with CMOS devices has been demonstrated. The new circuit-design technique offers better power-delay products compared with conventional CMOS and implements pipelining at the gate level without area or delay overhead. A signed-digit, full-adder chip has been fabricated that uses fewer devices than conventional CMOS chips. This chip should result in improved addition speed—a computational enhancement important for many DoD applications.

5.4.5 Single-Electron Metal Oxide Semiconductor Memory

Low-temperatures have traditionally been required to observe effects important to the operation of single-electron devices. In a program exploring the limits of electronic device technology, however, DARPA-supported researchers have recently developed the world's first single-electron, silicon-based MOS memory able to operate at room temperature. This novel memory element has demonstrated that a single bit of information can be stored using the smallest unit of electronic charge (a single electron), and that this unique device can operate even at room temperature.

In the demonstrated device, the memory is very similar in design to a traditional silicon floating-gate MOS nonvolatile memory, but the source-drain channel of the memory is so narrow that one electron on the floating gate can shield the entire underlying channel. This shielding creates a significant shift in the source-drain current-voltage characteristics and hence signals the storage of

a bit. Another novel aspect of the device results from the floating gate being physically very small; it thus represents a very small capacitance that requires a significant quantized voltage to store even a single electron. This voltage requirement greatly reduces the influence of electrical noise.

The fabrication of this innovative memory element is completely compatible with current CMOS techniques and is suitable for ultra-large-scale integration (ULSI). Numerous DoD applications that require the ultra-dense, massive memory enabled by this development will benefit from the potential demonstrated in this work.

5.4.6 Improved Thin-Film Ferroelectric Materials for Uncooled Infrared Detectors

Uncooled ferroelectric detectors used for infrared viewing are currently produced using bulk material that is pressed into wafers and thinned for detector processing. Although this technique is being used to produce detectors for uncooled IR cameras, the inherent detector sensitivity limits their application to medium-performance devices. Recently, researchers supported by DARPA have demonstrated thin-film ferroelectric material having detector properties consistent with those normally found only in high-performance uncooled IR systems. This important advance is based on new approaches to lead zirconate titanate (PZT) thin-film deposition that employ a metal-organic decomposition (MOD) technique; the material is spun onto the substrate using a process that is similar to the standard photoresist deposition process employed in integrated circuit manufacturing. This novel, production-compatible approach allows material to be deposited onto 4-inch substrates in layers having a thickness of 1,000 angstroms. After each thin layer is deposited, the material is subjected to pyrolysis at a temperature of approximately 500°C to remove organic materials, which could degrade pyroelectric properties. Thin films of PZT exhibiting a pyroelectric coefficient and dielectric constant sufficient for achieving a temperature sensitivity of 0.04°C are produced.

This work represents an important first step toward developing a high-performance, monolithic, uncooled sensor technology able to exploit the full potential of thin-film ferroelectric materials. Future work will include optimization of a rapid thermal annealing process compatible with integrated circuit production, and fabrication of thin-film ferroelectric focal plane arrays.

5.4.7 Wafer Fusion for Optoelectronic Devices

Recent DARPA-supported advances in gallium arsenide (GaAs) semiconductor diode lasers, which incorporate high-reflectivity mirrors during epitaxial growth of the material structure used to form the diode, have resulted in a new vertical-cavity, surface-emitting laser design that has a number of advantages over conventional designs, particularly for array applications involving optical interconnection of electronic systems. Extension of this new design to longer wavelength lasers based on InP materials, which are used in fiber-optic communication links, has been inhibited by difficulties in producing these materials. In particular, they require inordinately thick epitaxial films to achieve the required reflectivity (>99 percent). DARPA-supported researchers have demonstrated the application of a novel wafer-fusion technique that incorporates GaAs-compatible materials for the laser mirrors, with InP materials emitting at long wavelengths to achieve the world's first continuous, room-temperature operation of a long-wavelength (1,300 nanometers), vertical-cavity laser. The development of a practical, long-wavelength, vertical-cavity laser is expected to advance the application of fiber optics for optical interconnections in high-performance military information systems. This material breakthrough is also expected to have a number of applications where heterogeneous integration of dissimilar materials offers significant device performance advantages.

5.4.8 Wide-Bandgap Gallium Nitride Semiconducting Materials

The application of a newly developed wide-bandgap semiconducting material, gallium nitride (GaN), for very bright blue and green light emitting diodes has recently been demonstrated by DARPA researchers. These devices exhibit two orders of magnitude greater output intensity compared with competing semiconductor emitters, and they are a factor of three more efficient than incandescent lamps.

Using newly developed photo-assisted metal-organic chemical vapor deposition (MOCVD) techniques, high-pressure MOCVD systems, and hydride vapor phase epitaxy, researchers have demonstrated very high quality material (as reflected by the extremely high measured electron mobilities of 1,500 cm^2/V-sec). Other multilayer alloy material structures (aluminum gallium nitride (AlGaN)/GaN) have also been demonstrated. Laser structures composed of very thin films of indium gallium nitride (InGaN)/GaN, which form multiple quantum wells, have also been prepared and shown to exhibit stimulated laser emission when photo-pumped. Work to demonstrate an electrically contacted laser emitting in the blue-to-ultraviolet (UV) region of the spectrum—well beyond the range of current operation for practical semiconducting lasers—is in progress. The wide bandgap of these materials makes them particularly well suited for transistors designed to operate at high temperatures.

Application of this new class of materials offers great promise for order-of-magnitude performance improvements in many DoD systems due to their inherent properties, including high thermal conductivity, hardness, durability, high-temperature behavior, large charge mobility, and large electric field breakdown strength. These properties make them ideal candidates for a variety of applications such as solar-blind UV detectors for missile threat warning; laser readout for high-density optical memories, enhancing storage capacity by a factor of ten; portable chemical/biological agent detection systems; and high-power, high-temperature electronics, amplifiers, and switches.

5.4.9 Reduced Power Consumption in Embedded Microprocessors

Power consumption constrains performance of the processors used in air-cooled workstations as well as those in embedded defense applications. Much of the power is consumed driving the clock, a single electrical node. For example, the latest DEC Alpha processor dissipates about 40 percent of its 18-watt power budget—or more than 7 watts—in the single 56-cm-long transistor that drives its clock. Researchers supported by DARPA have developed a novel approach to driving clocks using resonant-circuit techniques. For this application, the clock node is designed to be a transmission line, and a small driver transistor impresses an electrical standing wave upon it. This new technology can drive the clock node in the Alpha processor with less than three quarters of a watt—a 90 percent reduction in power requirement. The size of the required clock driver transistor is similarly reduced by a factor of ten. The researchers are now transferring the technology to two U.S. computer vendors, SUN and DEC, to facilitate its availability for both military and nonmilitary systems.

5.4.10 Language Understanding

Information overload is a term frequently used to describe the flood of information that overwhelms modern-day planners and operators alike. To reduce the negative effects of information overload, DARPA has been investigating methods for automating the processing of multimedia

broadcasts, such as Predator video or TV news, with the objective of extracting specific information. To achieve efficient screening, the technology for understanding must include extraction of relevant information, classification, intelligent indexing, topic spotting and tracking, and summarization. To date, metrics-based tests have been established to evaluate emerging performance with a focus on core capabilities such as identifying names of organizations, persons, locations, dates, times, and monetary amounts. For the first time, a language-independent algorithm learned to extract information from news with a success rate greater than a hand-crafted, rule-based system. The new approach uses a statistical learning algorithm, in particular a hidden Markov model, to generalize from examples in context. This is an important milestone toward a new technology for multilingual, affordable, and accurate multimedia information understanding systems. Though developed for English first, the algorithm learned to perform well for Spanish solely from examples.

5.4.11 Tools for Detecting Software Defects

DARPA researchers have recently developed and tested a suite of tools for detecting software defects. The tools, which focus on concurrent, real-time, distributed Ada systems, provide improved capabilities for (1) generating test data and ensuring effective test coverage, (2) automatically checking test results, and (3) developing quality-assurance processes that integrate formal analysis and testing activities to achieve desired quality levels. This suite of tools has been applied by the developers and by other defense contractors to a wide variety of important DoD problems, including the identification of errors in missile simulation and radar signal processing software. The tool suite is being adopted by the Microelectronics and Computer Technology Corporation (MCC) in a consortium that includes Motorola, Lockheed Martin, Hughes, Southwestern Bell, Computing Devices International, and Nortel.

5.5 Ballistic Missile Defense Organization

5.5.1 Optical Gains in Quantum Dot Structures at Room Temperature

Quantum dot structures in advanced materials have yielded optical gain at room temperature for the first time. Hitherto, very low cryogenic temperatures had been required for such performance. This accomplishment potentially forms the basis for further advances in high-speed signal processing and optical communication important to many military operations. The research was a joint effort between the University of California at Los Angeles (UCLA) in material preparation and the University of Arizona (UA) in the evaluation of the device physics. Uniformly sized quantum dots were evenly distributed in a sol-gel matrix at UCLA, and the devices using the quantum dots were evaluated at the Optical Sciences Center at UA. Two-beam coupling was first obtained at cryogenic temperatures, but subsequent refinement of the quantum dot material finally yielded devices that work at room temperature.

5.5.2 Improved Contrast of Infrared Images Through Faster Algorithm

Researchers at Purdue University have developed a faster image-segmentation algorithm for identifying objects in a scene that has significant military utility, such as in automatic target recognition or image discrimination. For example, the algorithm—called BCDF (Bayesian conditional decision feedback)—would improve contrast in an infrared image taken by a sensor with poor quantum efficiency. To date, the algorithm has successfully demonstrated contrast improvement on synthetic imagery. It works by recursively calculating the best estimate of each pixel value in the scene

by combining data from nearby pixels. This fundamental approach is being focused toward several BMDO imaging applications.

5.5.3 Bright, Efficient Polymeric Light-Emitting Diodes

The first members of a new class of organic, polymeric light-emitting diodes (LEDs), operating in the orange-red to red spectral region, have been demonstrated at the University of Massachusetts. The LEDs show a high luminescence efficiency, bright intensity, and long-term emission stability. Their sequential, direct casting in multiple layers with different emission characteristics offers a future path to improved flat panel displays, which are widely used in military systems, including aircraft, ground vehicles, surface ships and submarines, and air- and missile-defense control stations. These polymers were specifically selected for ease of material synthesis and device processability. The chosen group of polymeric materials, their synthesis, the device configuration, and processing procedures were established by a team of chemists, polymer scientists, and device physicists at the university.

APPENDIX A

DoD BASIC RESEARCH PROGRAM

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APPENDIX B

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AAN	Army After Next
AASERT	Augmentation Awards for Science and Engineering Research Training
ACI	accelerated capability initiatives
AFB	Air Force Base
AFOSR	Air Force Office of Scientific Research
AI	artificial intelligence
AlGaAs	aluminum gallium arsenide
AlGaN	aluminum gallium nitride
ARO	Army Research Office
ASBREM	Armed Services Biomedical Research Evaluation and Management Committee
ASW	anti-submarine warfare
ATM	Asynchronous Transmission Mode
ATR	automatic target recognition
BAA	broad agency announcement
BMDO	Ballistic Missile Defense Organization
BOAS	blade-outer-air-sea
BRP	Basic Research Plan
C^3I	communications, command, control, and intelligence
C^4I	communications, command, control, computers, and intelligence
CBD	chemical/biological defense
CAV	composite armored vehicle
CBW	chemical and biological warfare
CMOS	complementary metal oxide semiconductor
CO_2	carbon dioxide
COIL	chemical oxygen iodine laser
CONUS	continental United States
DARPA	Defense Advanced Research Projects Agency
DCOR	Defense Committee on Research
DDDR&E	Deputy Director, Defense Research and Engineering
DDR&E	Director of Defense Research and Engineering
DEMIL	demilitarization
DEPSCoR	DoD Experimental Program to Stimulate Competitive Research
DEW	directed energy weapon
DoD	Department of Defense
DOE	Department of Energy
DRAM	dynamic random access memory
DRB	Defense Resources Board
DRS	Defense Research Sciences
DSTAG	Defense Science and Technology Advisory Group

DTAP	Defense Technology Area Plan
DURIP	Defense University Research Instrumentation Program
EEG	electroencephalogram
ELF/VLF	extremely low frequency/very low frequency
EM	electromagnetic
EO	electro-optics
EW	electronic warfare
EXCOM	Defense S&T Reliance Executive Committee
FED	field emission display
FET	field effect transistor
FFRDC	Federally Funded Research and Development Center
FIFO	first-in, first-out
FRI	Focused Research Initiative
GaAs	gallium arsenide
GaN	gallium nitride
GaSb	gallium antimonide
Ge	germanium
GEO	geosynchronous earth orbit
GHz	gigahertz
GICR	Government/Industry Cooperative Research
GMR	giant magneto-resistance
GPS	Global Positioning System
HBCU/MI	Historically Black College and University/Minority Institution
HFET	heterojunction field effect transistor
HFTA	High-Temperature Flowing Afterglow
HHS	Health and Human Services
HP	heteropolymer
HPM	high-power microwave
HSLA	high-strength low alloy
IFSAR	interferometric synthetic aperture radar
IHPTET	Integrated High Performance Turbine Engine Technology
ILIR	In-house Laboratory Independent Research
InGaN	indium gallium nitride
InP	indium phosphide
IR	infrared
IR&D	Independent Research and Development
IS	intelligent system
ISDN	Integrated Services Digital Network
JCS	Joints Chiefs of Staff
JLOTS	joint logistics-over-the-shore

JSEP	Joint Services Electronics Program
JWSTP	Joint Warfighting Science and Technology Plan
LANL	Los Alamos National Laboratory
LED	light-emitting diode
LIDAR	light detection and ranging
LLS	laser-line-scan
LO	low observable
LOTS	logistics over-the-shore
MCM	mine countermeasures
MEMS	microelectromechanical systems
MeV	million electron volt
MHD	magnetohydrodynamics
MIMIC	microwave/millimeter wave monolithic integrated circuit
MIT	Massachusetts Institute of Technology
MMW	millimeter wave
MOD	metal-organic decomposition
MOS	metal oxide semiconductor
$MoSi_2$	molybdenum disilicide
MURI	Multidisciplinary University Research Initiative
NASA	National Aeronautics and Space Administration
NASA–LeRC	NASA Lewis Research Center
NDE	nondestructive evaluation
NdFeB	neodymium iron boride
NLO	nonlinear optics
NOAA	National Oceanographic and Atmospheric Administration
NRL	Naval Research Laboratory
NSF	National Science Foundation
ODASA(R&T)	Office of the Deputy Assistant Secretary of the Army, Research and Technology
ODDR&E	Office of the Director, Defense Research and Engineering
ONR	Office of Naval Research
ONREUR	Office of Naval Research, Europe
OSD	Office of the Secretary of Defense
PBL	planetary boundary layer
PbTe	lead-telluride
PDE	partial differential equation
PEBB	power-electronic building block
PEM	polymer electrolyte membrane
POM	Program Objective Memorandum
PPS	polyphenylsulfone
PRET	Program for Research Excellence and Transitioning
PRG	Program Review Group
PZT	lead zirconate titanate

RAM	random access memory
RAP	radio access point
RF	radio frequency
RTD	resonant tunneling diode
S&E	science and engineering
S&T	science and technology
SAM	self-assembled molecules
SAR	synthetic aperture radar
SATCOM	satellite communications
SBIRS	Space-Based Infrared System
SCF	supercritical fluids
Si	silicon
SI_3N_4	silicon nitride
SiC	silicon carbide
SNR	signal-to-noise ratio
SPG	Scientific Planning Group
SRO	Strategic Research Objectives
STM	scanning tunneling microscope
STOL	short take-off and landing
SUNY	State University of New York
TARA	Technology Area Review and Assessment
T_c	critical temperature
TCP/IP	Transmission Control Protocol/Internet Protocol
TSRAM	transistorless static random access memory
UA	University of Arizona
UAV	unmanned aerial vehicle
UCLA	University of California, Los Angeles
UCSB	University of California, Santa Barbara
ULSI	ultra-large-scale integration
URI	University Research Initiative
URISP	University Research Infrastructure Support Program
USC	University of Southern California
UT	University of Tennessee
UUV	unmanned underwater vehicle
UV	ultraviolet
VLSI	very large scale integration
WMD	weapons of mass destruction
YAG	yttrium aluminum garnet
YBCO	yttrium barium copper oxide